ANALYSIS OF CHINOOK SALMON IN THE COLUMBIA RIVER FROM AN ECOSYSTEM PERSPECTIVE

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EXECUTIVE SUMMARY

ANALYSIS OF CHINOOK SALMON IN THE COLUMBIA RIVER FROM AN ECOSYSTEM PERSPECTIVE

Ecosystem Diagnosis and Treatment (EDT) methodology was applied to the analysis of chinook salmon in the mid-Columbia subbasins which flow through the steppe and steppe-shrub vegetation zones. The EDT examines historical changes in life history diversity related to changes in habitat. The emphasis on life history, habitat and historical context is consistent with and ecosystem perspective.

This study is based on the working hypothesis that the decline in chinook salmon was at least in part due to a loss of biodiversity defined as the intrapopulation life history diversity. The mid Columbia subbasins included in the study are the Deschutes, John Day, Umatilla, Tucannon and Yakima.

Conceptual Framework

A major part of the study's conceptual framework is the conservative assumption that functional relationships between life history diversity and habitat diversity are adaptive although the genetic component may be small. This assumption implies that complex habitats with a high degree of connectivity permit the development and expression of diverse life histories. Further, the relationship between life history and habitat is an important determinant of an ecosystem's potential capacity and its performance in terms of salmon production.

Juvenile life history patterns in chinook salmon are classified into one of two general patterns: the ocean and stream types. Ocean type life history exhibits a short freshwater residence, usually migrating to sea within six months of emergence. Fish exhibiting the stream type life history migrate to sea in the spring of their second year. The ocean type life history pattern is dominate and will be exhibited where there is sufficient growth opportunity for the juveniles after emergence. The stream type life history is determined in part by photoperiod at the time of emergence and growth opportunity. Under healthy habitat conditions, a population of juvenile chinook will exhibit several variations of the stream or ocean life history types. These variations constitute an important part of the species biodiversity.

An important part of the conceptual framework is the assumption that life history is the salmon's solution to survival problems in its habitat and that multiple life histories are the salmon's solutions to survival problems in a fluctuating environment.

The conceptual framework also incorporates the effects of natural production cycles on the observed changes in the abundance of chinook salmon. Conventional wisdom attributes the decline of Pacific salmon in the Columbia River and elsewhere in the Northwest to over harvest, habitat destruction and the side effects of artificial propagation. These factors certainly contributed to the declines. However, cyclic changes in productivity also played a major part in the declines. The interactions between natural fluctuations in productivity and human activities over the past 100 years probably increased the depth of the troughs and depressed the height of the peaks in salmon production.

Findings

Intensification of commercial exploitation of chinook salmon in the Columbia River began in 1866. Since then, the harvest of chinook salmon can be divided into four phases: Initial development of the fishery (1866 to 1888), a period of sustained production with an average annual harvest of about 25 million pounds (1889 to 1922), resource decline with an average annual harvest of 15 million pounds (1923 to 1958), and maintenance at a depressed level of production of about 5 million pounds (1958 to the present).

The patterns in abundance of chinook salmon described strictly in numerical terms mask an important shift in resource quality that took place between 1890 and 1920. Spring and summer chinook were declining and to maintain production, harvest shifted from spring and summer chinook to fall chinook salmon. Since the 196Os, increases in the survival of hatchery reared fish created another shift in resource quality. Salmon of hatchery origin now make up about 80% of the total adult run into the Columbia River.

The decline of spring/summer chinook early in this century was attributed to over harvest and habitat destruction with over harvest generally receiving the greater emphasis. However, spring and summer chinook were particularly vulnerable to the kind of habitat degradation that took place in the last decades of the 19th and early decades of the 20th centuries. Grazing and timber harvest stripped away riparian vegetation and dried up wetlands. In the high desert subbasins, the loss of riparian cover has significant effects on the quality of salmon habitat including structural complexity and temperature. Another important source of habitat degradation was gravity irrigation systems which diverted water from rivers at higher elevations for distribution to farms at lower elevations. Because of their different spawning distributions, spring and summer chinook salmon were influenced most by irrigation diversions. Juvenile chinook salmon migrating downstream in late spring and summer, at a time of high demand for water, were diverted into unscreened irrigation ditches and left to die in large numbers in watered fields.

The clearing or over grazing of riparian vegetation and draining of wetlands adjacent to stream channels, channel straightening and water diversions for irrigation fragmented the habitat of salmon in the midColumbia subbasins. The cumulative effects of development activities dewatered lower reaches of tributaries or elevated temperatures beyond the preference or tolerance of salmon. The combination of unscreened irrigation diversions and loss of riparian cover created thermal or physical barriers and caused a significant loss of productivity. The decline in productivity can be linked to the loss of the subyearling life history pattern.

CONCLUSIONS

A **A conceptual framework based on the relationship between life history and habitat is a useful approach to the analysis of salmon problems over large areas of the Columbia Basin.**

B **The capacity and performance of the Columbia River ecosystem relative to Pacific salmon fluctuates naturally at millennial, decadal and annual intervals. Annual fluctuations are generally recognized and taken into account in the design of restoration programs. An understanding of millennial fluctuations helps establish historical context but has little impact on program design. Decadal fluctuations in productivity have important implications to the design, implementation, evaluation of the recovery program and the realization of program goals. Fluctuations in capacity at decadal intervals are not being adequately addressed.**

C **Chinook salmon in the Columbia Basin underwent important qualitative changes in the late 19th and early 20th centuries and again after 1960. The first change was the decline of the spring/summer run fish and the second change was the growth in the proportion of salmon of hatchery origin.**

D **Harvest may have been over emphasized as the cause of the decline of spring/summer chinook. Habitat destruction probably played a much greater role in the decline prior to 1920.**

E **Habitat fragmentation eliminated the dominant ocean type life history pattern and contributed to the decline of the spring/summer chinook salmon. Habitat fragmentation is characterized by the occurrence of lethal temperatures or extreme low flows through the summer months in the lower reaches of subbasins. The loss of the ocean type life history pattern constitutes a loss of biodiversity.**

F The construction of mainstem dams increased habitat fragmentation by creating marginal migratory habitat in the mainstem Columbia River. Habitat was degraded through the conversion of a free flowing river to a series of reservoirs and through a change in normal flow patterns. The mainstem dams prevented any chance of recovery to the pre 1920 production levels.

G Restoration of spring/summer chinook salmon will require the restoration of habitats and habitat connectivity in both the mainstem and in the degraded subbasins.

IMPLICATIONS

A Management/restoration programs and the models or conceptual frameworks that those programs are derived from must account for natural fluctuations in habitat quality and salmon production. A failure to do so will at best reduce the possibility of successful restoration and possibly produce detrimental results.

B Monitoring of life history diversity in selected populations should be an important component of the regional monitoring and evaluation program.

C The use of EDT and its underlying conceptual framework gives important new insight into the decline of chinook salmon which has implications to the design of restoration programs.

D Habitat in portions of the mainstem and estuary of the Columbia has also been fragmented and degraded. Changes in flow patterns and development have altered the habitat quality and quantity in the mainstem and estuary further reducing life history diversity and productivity of estuarine dependent species such as chinook salmon. The application of EDT to other subregions in the basin should be considered.

E Habitat restoration in the upper reaches of subbasins might be targeted on life histories that did not make important contributions to the production of chinook salmon prior to habitat degradation. Improving the quality of remaining refugia habitats is not as important as restoration of connectivity -- improving the quality of habitat in the lower reaches of the subbasins.

F Management from an ecosystem perspective will require watershed-wide restoration programs that attempt to reconstruct historic habitats and life histories.

ANALYSIS OF CHINOOK SALMON IN THE COLUMBIA RIVER FROM AN ECOSYSTEM PERSPECTIVE

An Application of the Ecosystem Diagnosis and Treatment Methodology

> ***"About 30 years ago there was much talk that geologists ought to observe and not to theorize; and I well remember someone saying that at this rate a man might as well go in to a gravel pit and count the pebbles and describe the colors. How odd it is that anyone should not see that all observation must be for or against some view if it is to be of any service"*** **(Darwin and Seward 1903 cited in Mayr 1991 p. 9).**

INTRODUCTION

Purpose

The purpose of this report is to review the status of chinook salmon in several subbasins within the steppe and shrub-steppe vegetation zone of the Columbia **Basin. The study looks at the decline of chinook salmon through an analysis of changes in life history diversity as related to changes in habitat quality. This approach is seldom used and it focuses on the historical changes in the environment in relation to changes in populations and their structure. The emphasis on life history and habitat and their historical context is consistent with an ecosystem perspective (Lichatowich et al. 1995).**

Our basic premise is that the life history patterns of a population are a unique **outcome of the habitat, particularly habitat complexity and connectivity and the population's genetic structure. Life history is the population's solution to survival problems in its habitat and multiple life histories within a population are the solutions to survival problems in a fluctuating environment. The interaction between life history and habitat is a major determinant of productivity and therefore provides a productive framework for the analysis of the historic decline of chinook salmon. Since it is not a conventional approach, it could yield unconventional insights into the causes of the decline and point to alternative restoration strategies.**

The methodology employed in this study is based on the ecosystem diagnosis and treatment procedure (Lichatowich et al.1 995), a broad approach to the development of salmon restoration plans which was derived from the Regional Assessment of Supplementation Project (RASP) (1992). To date, the approach used here has been applied to individual subbasins. However RASP (1992) stated that it could be applied to higher levels in the physical-biological hierarchy. The use of a consistent conceptual framework to evaluate declines and plan restoration is important to ensure that program measures are complimentary and consistent at the subbasin, subregional and regional or watershed levels. This project applies the approach to large ecological zone comprised of several subbasins. The results should be instructive to those attempting subregional and regional planning (e.g. NPPC 1994).

The study is based on the working hypothesis that declines in abundance are at least in part due to a loss of biodiversity defined as the intrapopulation life history diversity of chinook salmon. The mid-Columbia subbasins included in the study are the Deschutes, John Day, Umatilla, Tucannon and Yakima (Figure 1). The Walla Walla River was not included although it is in the same environmental zone which is characterized as steppe or shrub-steppe (Franklin and Dryness 1973) (Figure 2) within the Cascade rain shadow (Figure 3).[1] This particular study area was selected because rainshadow habitats are more vulnerable to the consequences of human development (Lichatowich 1993a). The analytical method employed in this study is a modified version of the Patient-Template Analysis (PTA) described by RASP (1992) and Lichatowich et al. (1995).

The study is comprised of five parts:

(1) <u>Regional Environmental and Life History Patterns</u>

This section presents a description of natural cycles in climate and productivity in the ocean and freshwater, a general description of chinook salmon life histories, and the factors influencing the expression of those life histories. This section establishes the conceptual framework for the study.

(2) <u>Template Description</u>

RASP (1992) defined the template as a description of healthy habitat and life histories in a subbasin. In this report the template describes the historic abundance of chinook salmon in the Columbia Basin, salmon habitat in the early decades of this century and historic life history patterns of chinook salmon in the study area. The template covers the period from predevelopment to 1940. Habitat degradation and stock

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[1] The definition of mid-Columbia used here is based on ecological and environmental criteria and may differ from other definitions of the mid-Columbia basin that are in use.

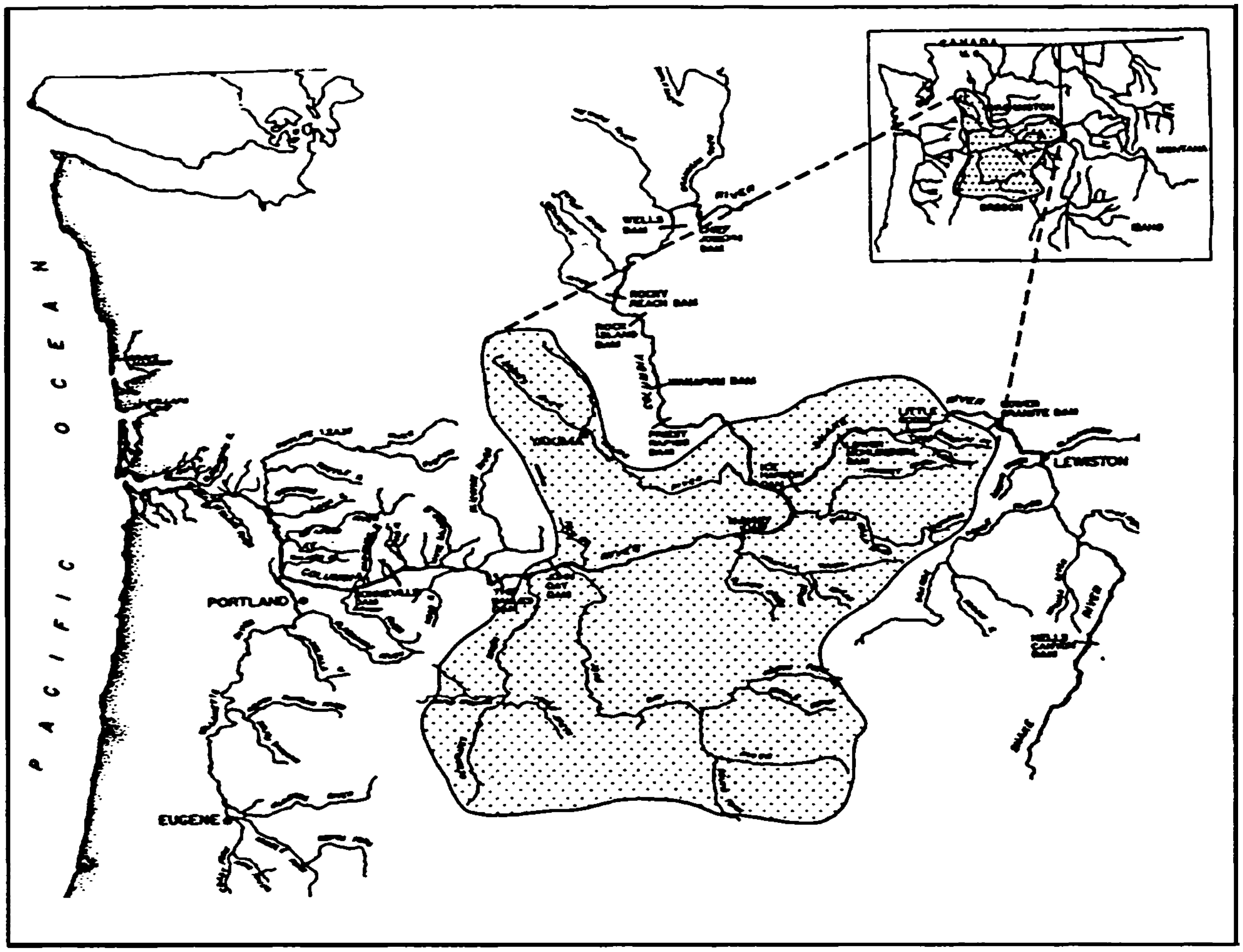


Figure 1. The Columbia River Basin. The area and streams included in this study are highlighted.

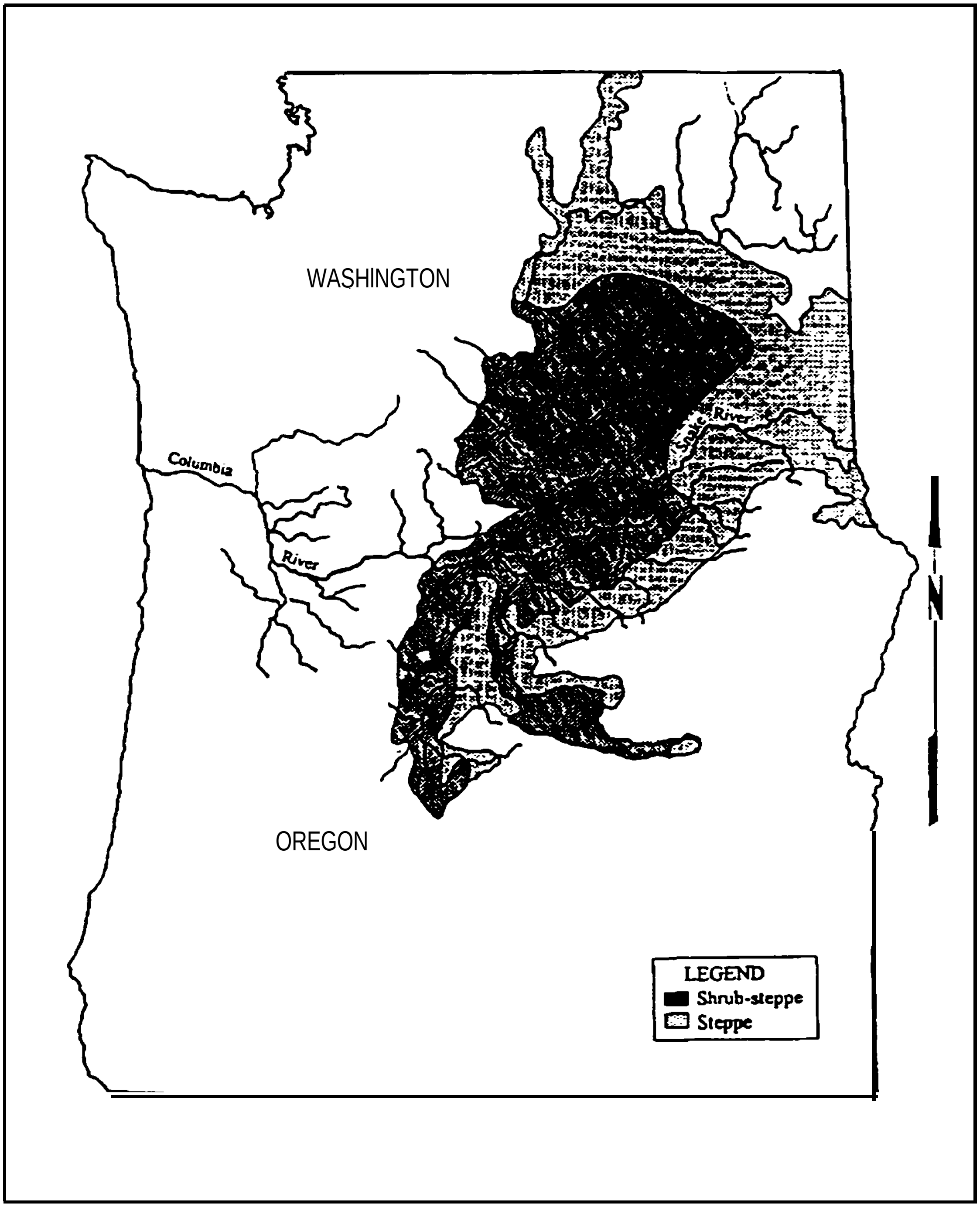


Figure 2. **The shrub--steppe and steppe vegetation zone in the mid-Columbia Basin. (From Franklin and Dryness, 1973, see Figure 1 for names of the subbasins.)**

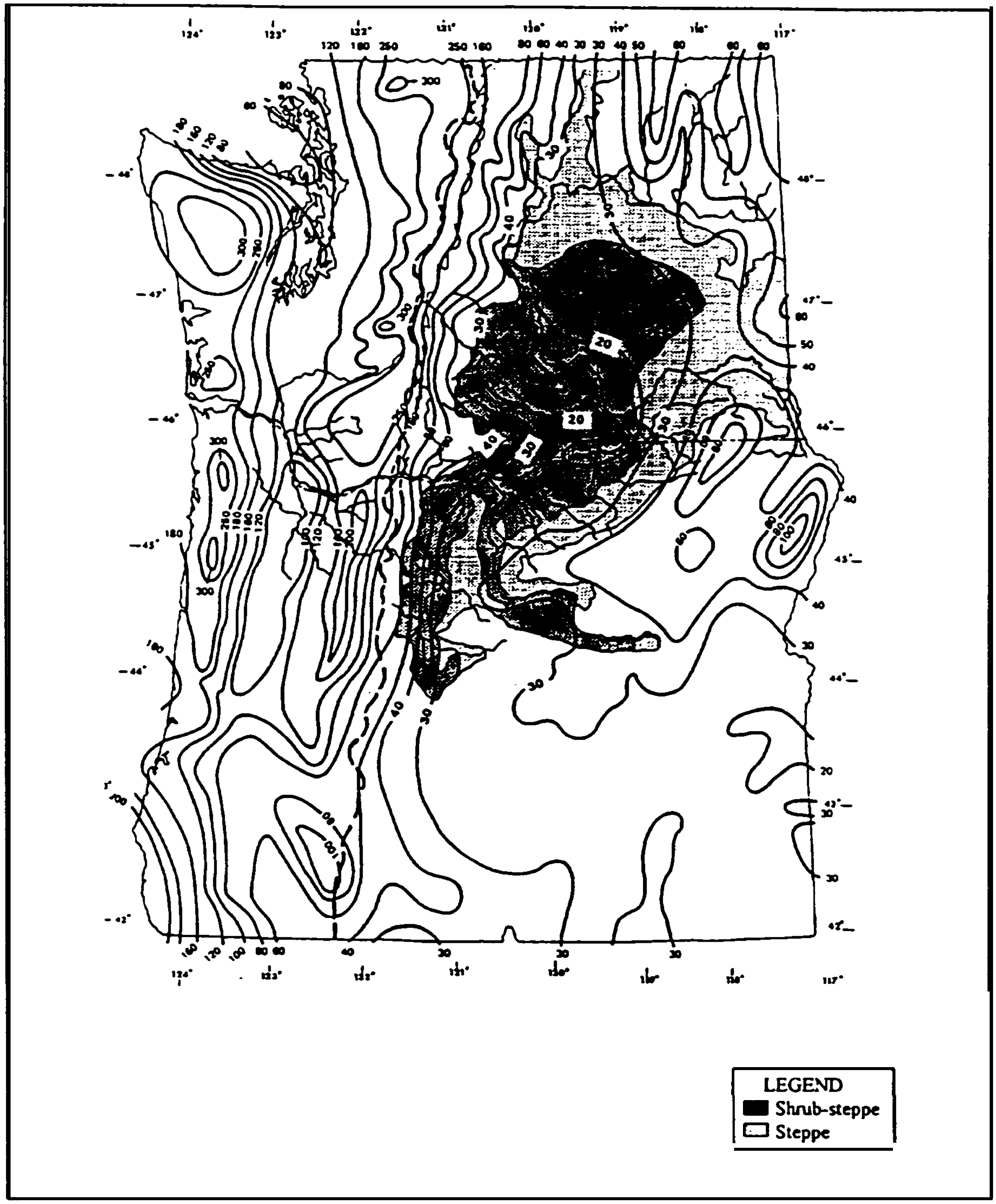


Figure 3. **The Cascade rainshadow in relation to the study area illustrated by the. isohyetal map of mean annual precipitation superimposed on the steppe and shrub-steppe vegetation zone. Precipitation in cm. (From Franklin and Dryness, 1973)**

depletion took place prior to 1940. However, the decade of the 1940s was a major turning point for the river's salmon populations because during and after that decade, the river underwent major transformation as the basin's hydroelectric potential was developed. A direct loss of 31% of the historic salmon habitat was attributed to water development projects (NPPC 1986).

(3) Patient Description

The patient describes the current (post 1940) abundance of chinook salmon in the basin and study area. Current life histories of chinook salmon and current status of salmon habitats in the subbasins within the study area are also described.

(4) Diaanosis

The diagnosis compares the patient and template to identify constraints on salmon production.

(5) Discussion

The discussion evaluates the working hypothesis and its critical uncertainties.

Patient-Template Analysis - Basic Concepts

Since PTA is a relatively new approach to restoration planning, a brief review of its important concepts is appropriate. PTA was originally developed to determine when supplementation is an appropriate restoration strategy and to help managers plan for the most effective use of supplementation in salmon restoration (RASP 1992). However, the basic approach has utility beyond supplementation including the development of habitat rehabilitation plans (Lichatowich et al. 1995). PTA is currently being applied to salmon restoration planning in the Yakima, Lemhi and Grande Ronde rivers in the states of Washington, Idaho and Oregon, respectively.

The template describes healthy habitat and life history relationships and the patient describes existing status of the habitat and life history of the population to be restored. The template is a pattern against which the present condition (patient) and the proposed future condition (restoration objective) are compared to identify production constraints and reasonable expectations for increased performance through natural or artificial production.

The template description should not be confused with the restoration objective. The template describes the historical performance of target populations in a watershed. The objective describes that part of the template that management activities will attempt to restore. In a few cases the template and objective will be the same, in very few cases the objective might exceed the template, and in most cases, the objective will represent only a part of the original performance.

A principal purpose of PTA is to assist in the identification of constraints on salmon production. Once production bottlenecks are identified appropriate remedial actions can be selected. PTA is based on two critical assumptions: 1) Population infrastructure observed or measured as life history diversity is an important determinant of a population's performance; and 2) the physical and biological elements comprising a watershed or ecosystem are organized in a hierarchical system which has to be considered when setting the scale of restoration planning and implementation.

Population Infrastructure

To achieve sustainable recovery of degraded salmon populations, an important goal of restoration programs should be to restore functional relationships that determine a system's potential productive capacity. Management programs (e.g., harvest regulations, hatchery operations and habitat protection) must enhance the performance of target populations of salmon within the watershed or subbasin. Important functional relationships include life history variants that adapt a population to its habitat.

An important determinant of a system's productive capacity is the degree to which its component salmon populations are adapted to the range of environmental conditions encountered in the subbasin, mainstem, estuary and nearshore ocean. In the Northwest, salmon populations have adapted to an extremely wide range of habitat conditions – streams flowing through deserts and rain forests; tidal streams and high elevation headwaters. The adaptive relationship between a salmon population and its habitats can be diminished or destroyed in three ways:

(1) **Human activities that shift environmental conditions (e.g., cover, temperature, hydrograph, and substrate composition and stability) so there is little overlap with the range of conditions to which the population has adapted. Natural catastrophic events can also change habitat faster than the population can adapt.**

(2) **The habitat may not change but the stock's genetic structure and therefore its adaptiveness might be altered by management practices such as selective fisheries or hatchery practices.**

(3) A combination of 1 and 2 above.

All salmon habitats naturally undergo changes in quality due to natural processes. Adaptation implies that a population with a history of exposure to natural fluctuations in habitat quality has retained in its genetic structure the potential to express the traits needed to survive and remain productive within the range of the historic natural change. Life history studies are one way to observe the expression of those traits. Life history diversity is a mechanism populations use to “spread the risk” of mortality in fluctuating environments (Den Boer 1968).

The genetic infrastructure of a population is the product of selection, straying, mate selection and random process. Variability in the infrastructure may be partitioned spatially and temporally among population segments (Gharrett and Smoker 1993a) and observed as the timing and distribution of life history events such as adult migration and spawning and juvenile rearing and migration.

Life history traits such as migration timing may be the expression of quantitative genetic variation, a passive response to the environment or a combination of both genetics and environment. It is not easy to confirm the genetic basis of life history traits (Gharrett and Smoker 1993b) or that the traits are adaptive (Taylor 1991). Consequently geneticists have often ignored the study of quantitative traits (life histories) and focused on selectively neutral qualitative traits which can be examined through biochemical studies of allozyme variation (Gharrett and Smoker 1993b). Some parallel studies of allozyme variation and life histories have been completed. For example, the timing of juvenile and adult migration has been related to genetic variation (e.g., Gharrett and Smoker 1993a and Carl and Healey 1984). The study of life history traits and their genetic basis should receive more emphasis.

A cornerstone of the PTA is the conservative assumption that functional relationships between life history and habitat diversity are adaptive and have a genetic basis, although the genetic component may be small, i.e., some life history traits may have a strong environmental component. This assumption implies that complex habitats with a high degree of connectivity permit the development and expression of diverse life histories. Further, the relationship between life history and habitat is an important determinant of a system’s potential capacity and its performance in terms of salmon production.

Hierarchical Organization

Biologists often view the biological systems that support and produce important fish species such as Pacific salmon as having different levels of organization (Warren 1971). Two forms of biotic hierarchical organization are: 1) Physiological system, individual organism, population and community; and 2) the trophic hierarchy of producers, consumers and decomposers. The physical system can also be divided into a hierarchical structure: Pool/riffle, reach, tributary and watershed. Although all levels of biological organization interpenetrate, managers often concentrate their efforts and define their programs within the limits of specific spatial/temporal scales and particular levels in a hierarchy (Warren 1971, O'Neill et al. 1986).

RASP (1992) suggested that PTA can be applied to restoration planning at various levels in the physical-biological hierarchy comprising the Columbia River Ecosystem. However, to date, PTA has been applied only at the individual subbasin/population level of organization. This study is the first attempt to extend the application of PTA to an ecological region comprised of several subbasins and populations. A planning process that can be applied at all levels in a system's hierarchical organization promotes internal consistency among program elements. Internal consistency is a prerequisite to the design of an efficient monitoring and evaluation program.

Selecting the appropriate level in the hierarchy to focus restoration planning is basically a problem of setting ecosystem boundaries. The boundaries will vary depending on the problem being addressed. For example, the Council's Fish and Wildlife Program (Northwest Power Planning Council (NPPC) 1987 and 1992) should define a boundary equivalent to the Columbia River watershed. Monitoring and evaluation might be designed to track progress toward program goals on a regional level where as the design of individual restoration projects focuses on subbasins or tributaries within subbasins. The spatial/temporal scale of the perturbation causing the problem that restoration is trying to correct should determine the spatial/temporal boundaries for planning purposes. A region-wide decline in production due to climate fluctuation cannot be adequately addressed through site specific supplementation projects. Managers must avoid the trap of selecting scales of convenience rather than scales at which the ecosystem is responding (O'Neill et al. 1986).

Often, in response to political pressure or the pressure to resolve immediate crises, management agencies compress the spatial/temporal scales of problem definition, management, and restoration planning. This year's harvest and allocation debates are the center of attention; habitat that is being destroyed today needs protection; hatchery managers want to release this year's production in healthy condition; and research/restoration programs become lists of projects to meet immediate needs instead of integrated programs based on a conceptual framework of appropriate spatial/temporal scale. Although the immediate problems are often the result of factors operating on broader time and space scales, it is often more convenient to treat them as simple isolated events. By specifically calling attention to history and ecosystem boundaries, PTA attempts to avoid the myopia that can creep into restoration planning.

REGIONAL CLIMATE AND LIFE HISTORY PATTERNS

The evaluation of habitat quality is almost always limited in temporal and physical scale. Smith (1993), Sedell and Luchessa (1981) and McIntosh (1992) are exceptions, i.e., those studies present analyses of habitat quality over large spatial/temporal scales. Selecting the appropriate scale is an important decision in any study of ecological systems (O'Neill et al. 1986). This is particularly true where system capacity and the performance of important components (e.g. salmon) are influenced by decadal or longer climate fluctuations. Beamish and Bouillon (1993), Lawson (1993) and Thompson (1927) describe the implications to management and problems of interpretation posed by the existence of long-term productivity cycles. This review of salmon abundance, life history and habitat in the Cascade rainshadow would be incomplete and possibly misleading without consideration of the long-term productivity cycles that influence performance at all levels in the hierarchical organization of the mid-Columbia River ecosystem.

Productivity Cycles

Climate, habitat and salmon production in the mid-Columbia Basin have fluctuated on a millennial scale (Figure 4). Using paleoscientific methods, more specifically, the species composition and growth of freshwater mussels found in shell middens in archaeological sites in the Columbia Basin, Chatters et al. *(in press)* concluded:

- Flows in the Columbia River were 30 to 40 percent below current levels >6,000 years before the present. During a cool and wet period 2,300 to 3,400 years before the present, flows were 30 percent above current levels.

- During the period from 7,900 to 5,500 years ago, the annual summer freshet ended by late June. Later, (3,400 to 2,300 years ago) the freshet extended into August.

- Prior to 3,900 years before the present water temperature was above 10°C for 200 days a year. Temperatures have dropped to less than 130 days above 10°C at the current time.

- Sedimentation was much higher 6,000 years ago.

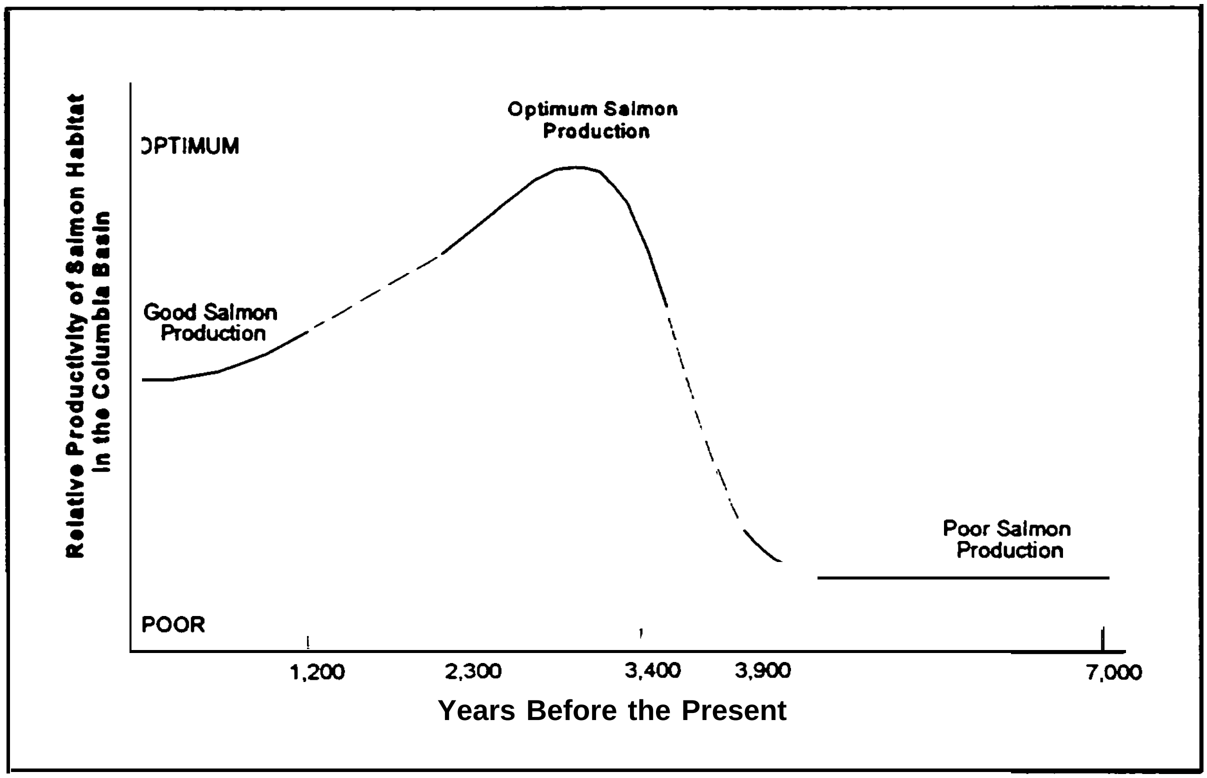


Figure 4. **Relative productivity of Pacific salmon in the Columbia Basin during prehistoric times. Based on Chatters et al. *(in press).* Dashed lines indicate periods where data are lacking.**

These patterns generally correspond to the occurrence of salmon in archaeo faunas at sites of prehistoric human occupation in the Columbia River. Archaeo fauna was comprised of a higher percentage of salmon remains during periods

identified as favorable to salmon production and salmon remains comprised a smaller percentage of Archaeo fauna during periods of unfavorable conditions (Chatters et al. *in* press) (Figure 4).

The evidence presented by Chatters et al. *(in* press) strongly suggests that on a millennial scale the evolution of the Columbia River ecosystem has followed a nonlinear trajectory. This environmental history suggests a connection with current problems. Historically, a natural change in the duration of the summer freshet probably influenced the timing of juvenile salmon migrations in much the same way that a change in the hydrograph due to large storage reservoirs has altered salmon migration and survival today (e.g., NPPC 1994).

Three recent papers present evidence for decadal scale fluctuations in climate and fisheries productivity in the Northeast Pacific: 1) Primary and secondary production and biomasses of pelagic fishes in the California Current fluctuate on a 40 to 60 year oscillation (Ware and Thomson 1991); 2) the abundance of salmon in the North Pacific corresponds to the long-term fluctuation in the Aleutian low pressure system (Beamish and Bouillon 1993); and 3) survival of coho salmon in the Oregon Production Index (OPI) is determined by the intensity of coastal upwelling (Nickelson 1986) which at least partially explains a 50 year cycle in coho salmon (*Oncorh ynchus kisutch*) production (Lichatowich *in press).*

Ware and Thomson (1991), Beamish and Bouillon (1993) and Nickelson et al. (1986) analyzed data collected after 1900 which was after the commercial salmon fisheries were well developed and severe habitat alteration had already occurred. However, an index of the standing stocks of pelagic fishes in the California Current is available for a 200 year period extending back prior to the commercial salmon fisheries. Historic standing stocks of pelagic fishes (hake, *Merluccius productus;* sardine, *Sardinops sagax*; and anchovy, *Engraulis mordax*) were reconstructed from scales contained in core samples taken from anaerobic sediments (Soutar and Isaacs 1974 and Smith 1978) (Figure 5). Those data show two features relevant to this study: 1) A 200 year peak in standing stocks near the turn of the century was followed by a 200 year low in standing stocks in the 1930s and 1940s, and 2) the magnitude of the change between the peak standing stocks around 1900 and the lows in the 1940s was the largest in the 200 year data set. The Oregon harvest of coho salmon parallels the trend in marine standing stocks (Figure 5).

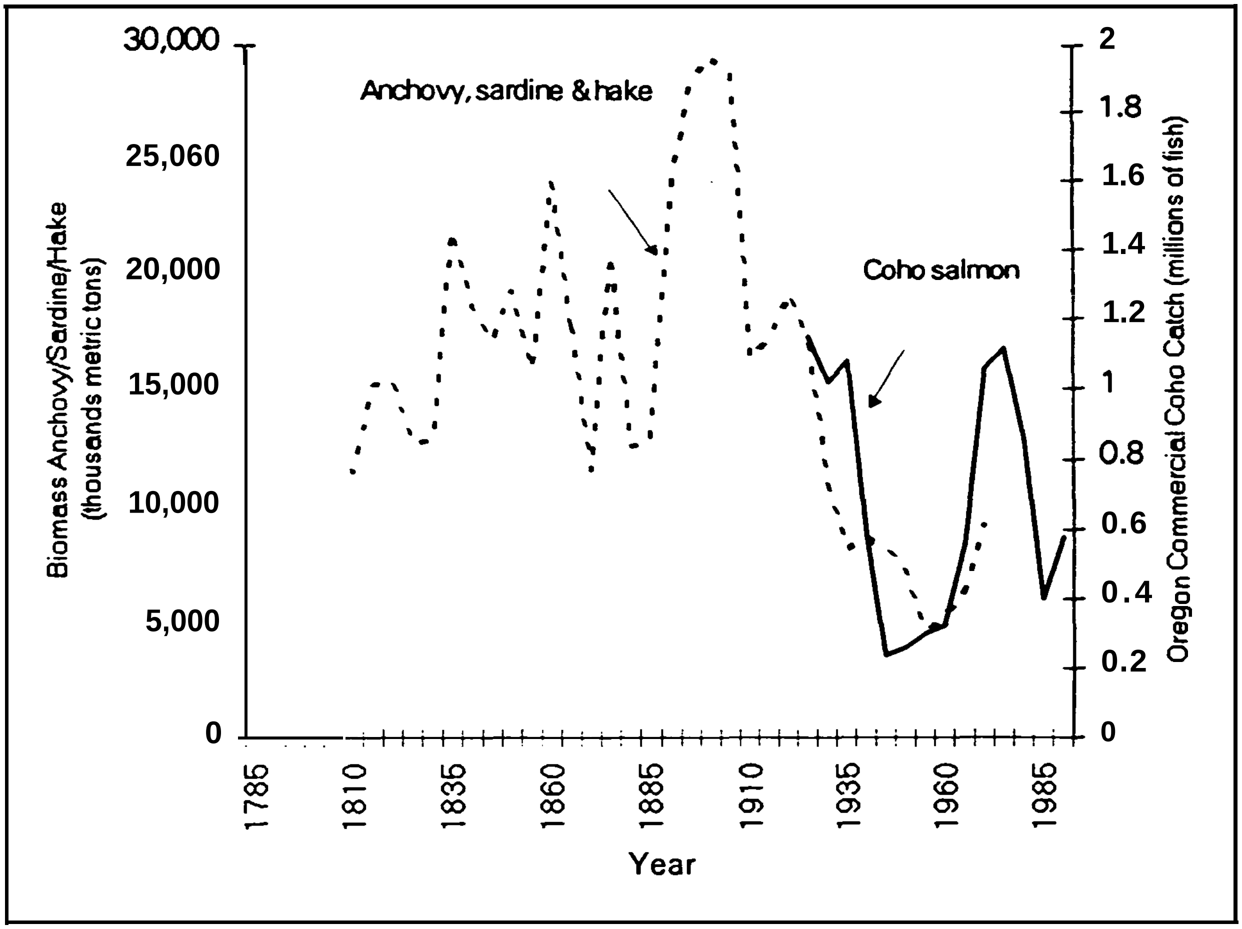


Figure 5. Total biomass of anchovy, sardine and hake in the California Current in thousands of metric tons. Standing stocks inferred from contemporary stock size and scale deposition rates in 18th and 19th centuries. (From Smith 1978) Commercial catch of coho salmon in millions of fish. Annual coho salmon harvest averaged by 5 year intervals. (Taken from Lichatowich 1993b)

Decadal fluctuations in the catch of coho salmon and standing stocks of pelagic fishes in the California Current correspond to indices of climate in the Columbia River Basin (Figure 6). Historic climate inferred from spacing of growth rings on trees is an index of the quality of the salmon's freshwater habitat. A period of cool-wet weather especially in the Snake River around 1900 was followed by a severe hot-dry period which lasted through the end of the data record in the mid-1940s. A different study which used a larger sample of trees covering a greater

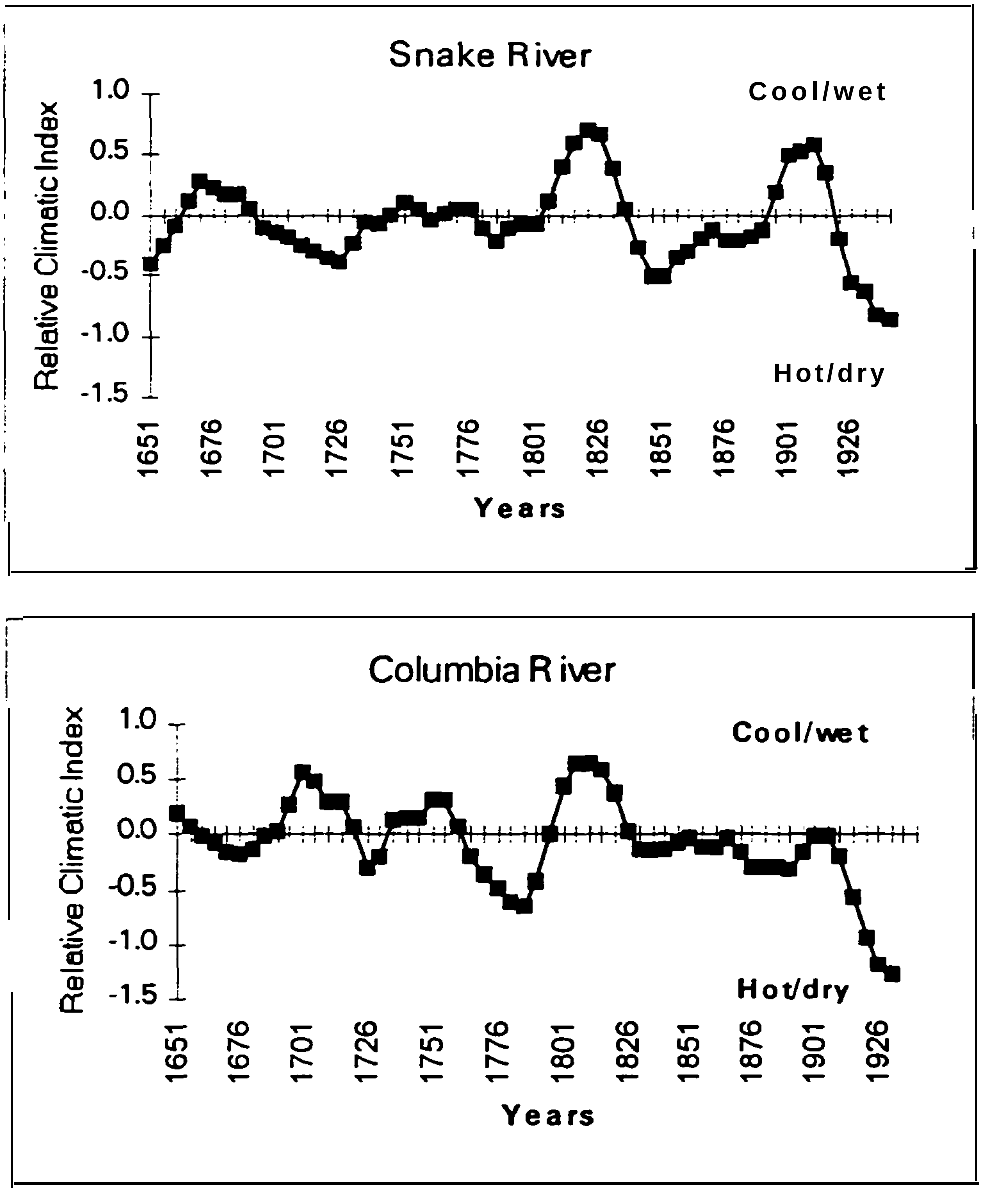


Figure 6. Fluctuation in an index of climate inferred from growth rings of trees in the Columbia Basin. Shown are five year moving averages of relative departures from a 270 year mean. Positive departures indicate cool/wet climate and negative departures indicate hot/dry climate. (From Fritts 1965)

geographical area in the Columbia basin also showed the higher level of precipitation around 1900 followed by declines through 1920s, 1930s and 1940s (Graumlich 1981 I. Reconstruction of historic temperatures in the Andrews Forest, Oregon (Figure 7) shows periods of cool temperatures in 1892-l 920 and 1947-l 976. Warm temperatures prevailed in 1921-l 946 and since 1977 (Figure 7).

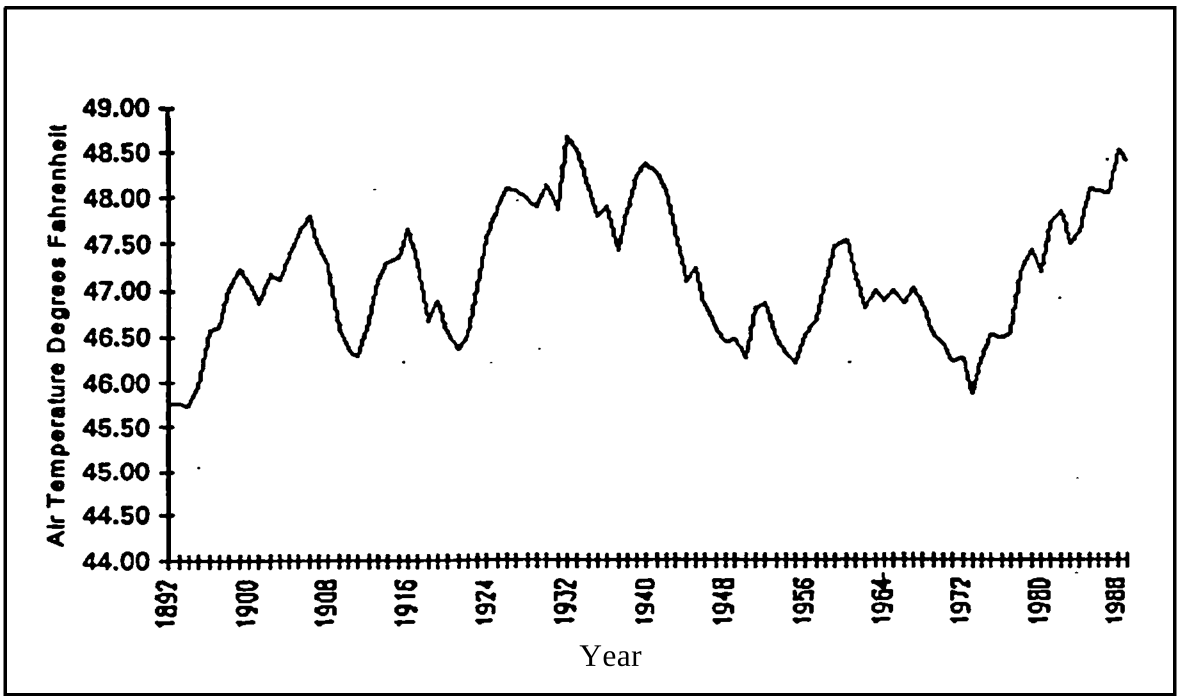


Figure 7. Reconstructed annual mean temperature in Andrews Forest in Oregon's central Cascades. (From Greenland 1993)

Large scale climate change probably influenced salmon production through changes in quality of both freshwater and marine environments during 1900-l 940. Commercial landings of chinook, coho, sockeye *(Oncorhynchus nerka)* and chum *(Oncorhynchus keta)* salmon in the Columbia River and chinook and coho salmon in Oregon coastal streams were in decline between 1920-1940 (Figures 8-9). In addition, the catch of chinook and coho salmon in Puget Sound showed significant declines between 1896-1934 (Bledsoe et al. 1989) (Figure 10). The preceding suggest that salmon were in general decline in the Northwest in the period 1920-1940 and the decline was in part due to a long-term fluctuation in climate. The current decline of salmon to historic low levels appears to correspond to a shift in climate that started about 15 years ago (Figure 7). The greater depth of the current production trough reflects increased habitat degradation.

The salmon fishery developed rapidly between 1880-1900 during a period of high productivity in the marine environment and favorable climate in freshwater areas. Those conditions probably established harvest expectations that could not be maintained in the long term (Lichatowich *in press).*

Conventional wisdom attributes the decline of Pacific salmon in the Columbia River and elsewhere in the Northwest to overharvest, habitat destruction and the side effects of artificial propagation. They were certainly major factors in the decline. However, if managers are to develop an understanding of the mechanisms of the decline and develop a sound approach to restoration, they have to incorporate into their analysis and planning the influence of cyclic changes in productivity. The extended ecosystem (fresh water, estuarine and marine habitats) of salmon from the Columbia Basin fluctuates in productivity at annual, decadal, and millennial scales. The interactions between natural fluctuations in productivity and human activities over the past 100 years probably increased the depth of the troughs and depressed the height of the peaks in salmon production (Figure 11).

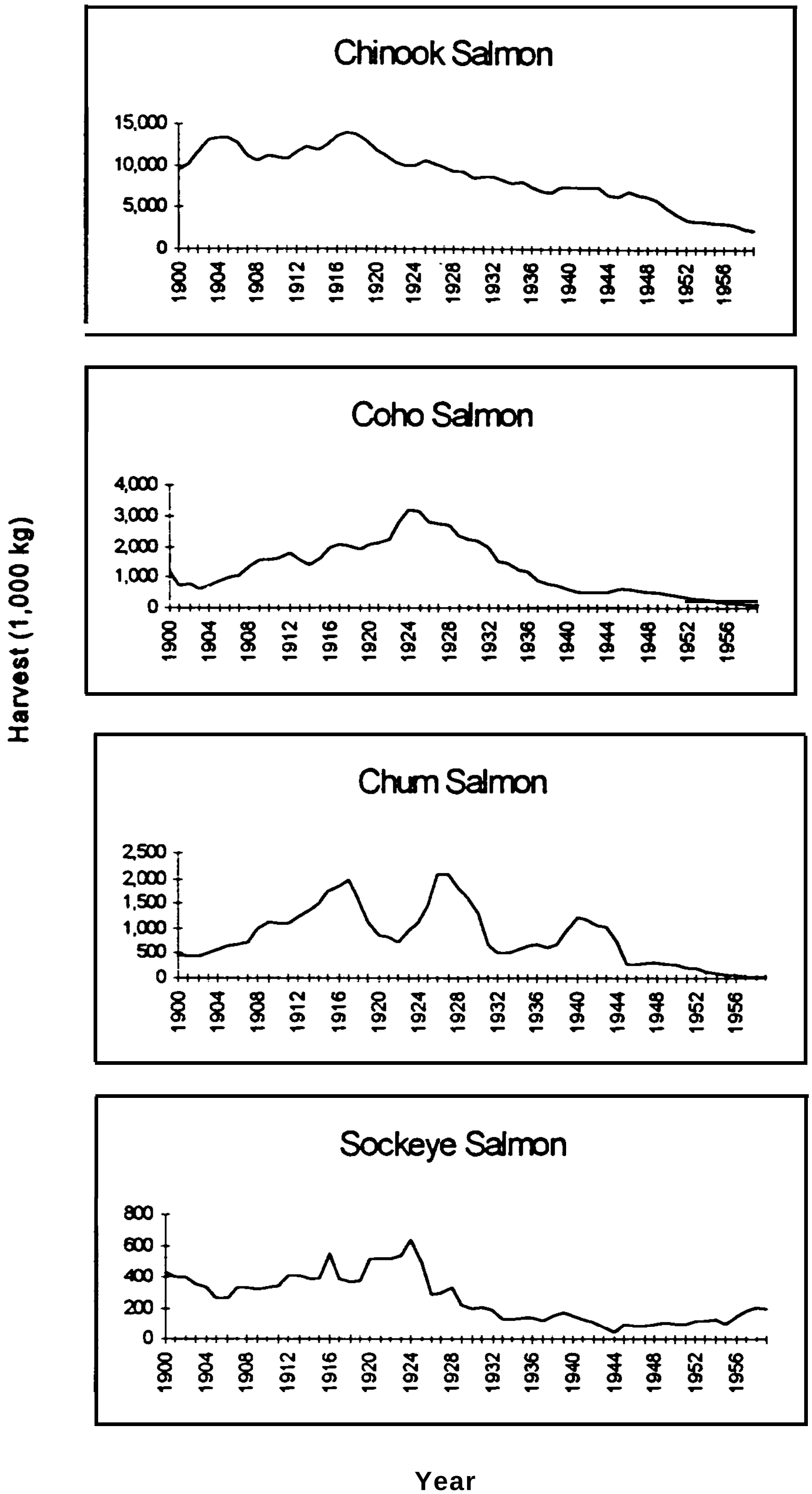


Figure 8. **Five year moving average of commercial salmon harvest (thousands of pounds) in the Columbia River. (From Beiningen 1976)**

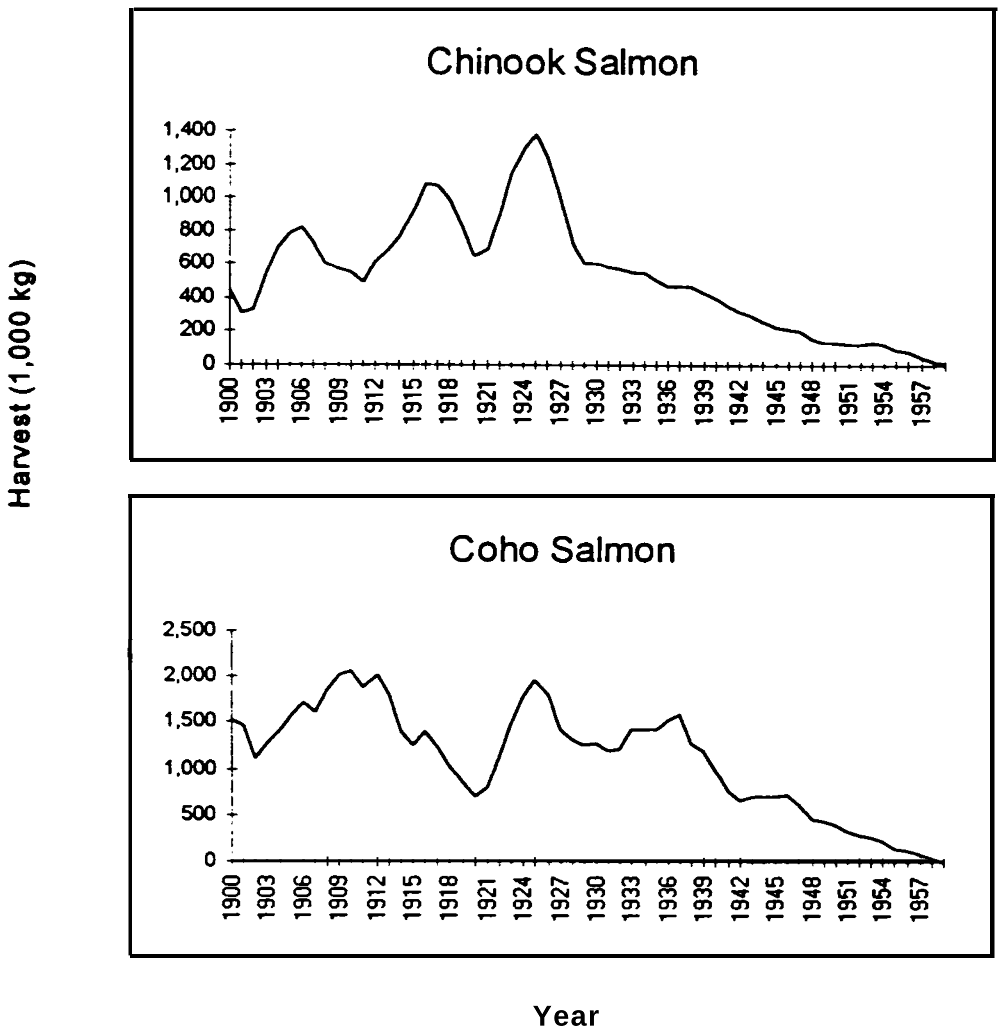


Figure 9. Five year moving average of the commercial chinook and coho salmon harvest in Oregon coastal rivers. (From Mullen 1981 and R. Mullen, unpublished data, Oregon Department of Fish and Wildlife)

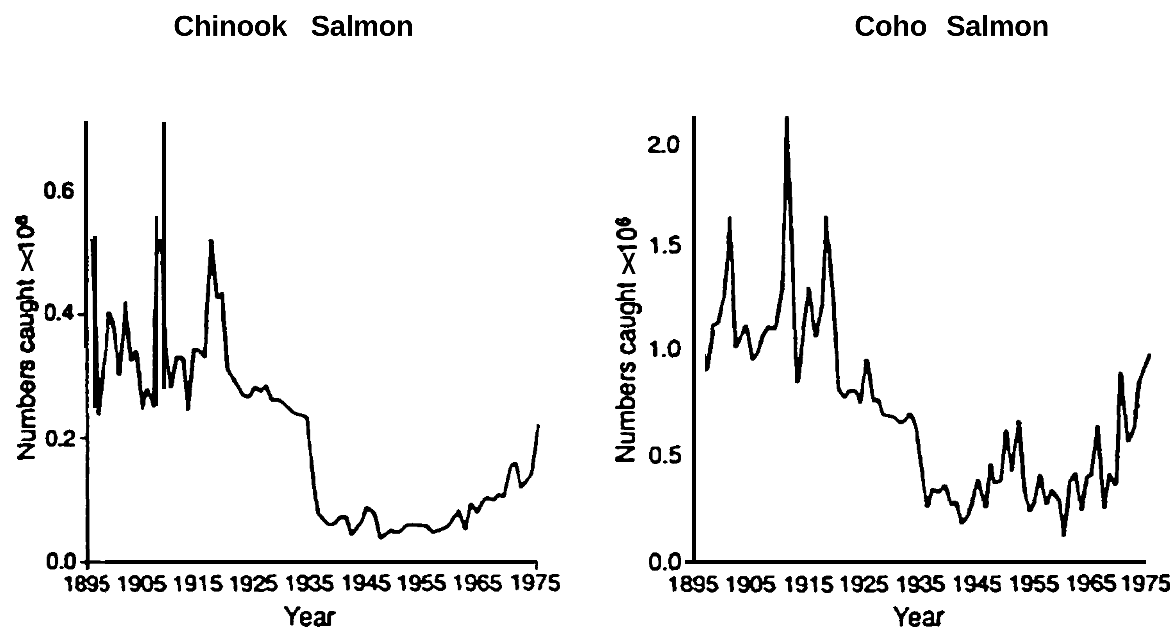


Figure 10. Catch of non-hatchery Puget Sound coho and chinook salmon. (From Bledsoe et al. 1989)

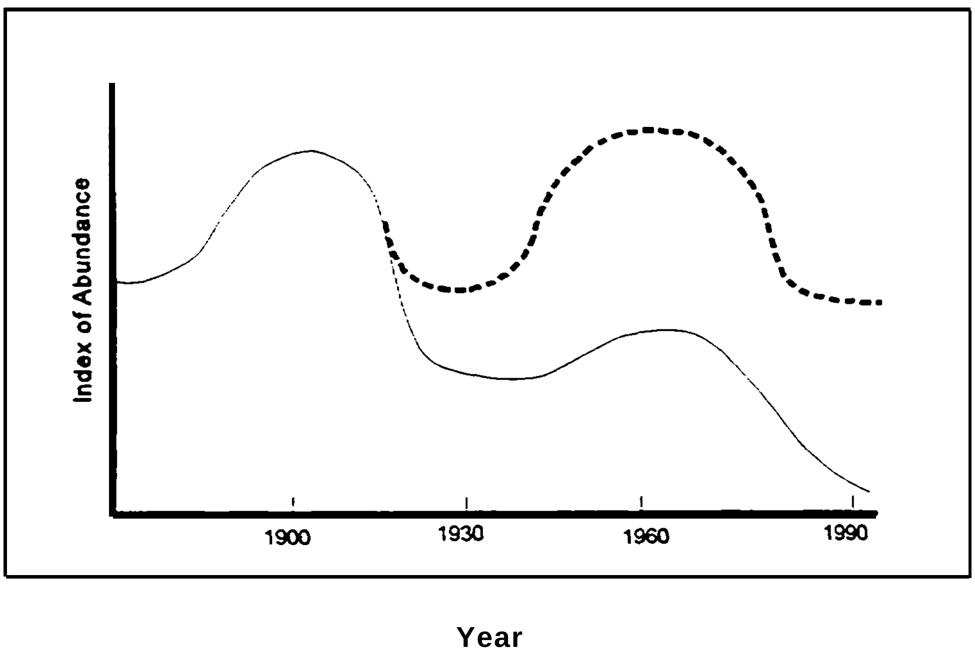


Figure 11. Hypothetical representation of salmon abundance in the Northwest over the last 150 years. The solid line illustrates the response of salmon to natural fluctuations in climate and productivity. The dashed line represents the probable production without intensive harvest, habitat destruction, and the negative effects of hatcheries.

LIFE HISTORY

"Life histories lie at the heart of biology, no other field brings you closer to the underlying simplicities that unite and explain the diversity of living things and the complexity of their life cycles. . . . Its explanatory po wer, barely tapped, could reach as far as communities" (Stearns 1992, p. 9)

Life histories are comprised of demographic traits such as age at maturity, mortality schedules, size and growth (Stearns 1992). In salmon, the interaction between demographic traits and migration within the salmon's extended ecosystem creates additional life history traits such as the age and size that juveniles migrate to sea, growth and maturity during ocean migrations and age and timing of spawning migrations. Life history traits are directly related to reproduction and survival and, therefore, are an important link between phenotype and genotype. They are a link between the fitness imparted by life history variants and the genetic consequence of differences in fitness among those variants (Stearns 1992).

Since habitats are templates for the organization of life history traits (Southwood 1977) each population's life histories must be considered in the context of its habitat. The expression of life history diversity in a complex and connected habitat structure is an important component of the adaptive capacity of the population or stock especially in fluctuating environments (Gharrett and Smoker 1993b). Diversity in the face of environmental uncertainty is the means by which the population spreads the risk of mortality and dissipates the probability of a catastrophic extinction (Den Boer 1968). The life history-habitat relationship is not static, it is a co-evolutionary process. Suitable habitats are colonized by appropriate life histories, and as habitats change, those life histories lose their fitness and cease to exist or are replaced by other life histories (Weavers 1993). Intrapopulation life history diversity distributes animals among favorable habitat patches similar to the way individual populations are distributed among habitat patches within a metapopulation structure (Hanski and Gilpin 1991).

The development and maintenance of life history diversity is a function of the habitat, genetic structure of the population and external selection factors. In Pacific salmon, habitat change, a loss or shift in life histories, and a change in fitness can result from natural or human causes. Long-term fluctuation in climate, and catastrophic events such as land slides, volcanism and fire are natural events that alter habitat availability and quality and the fitness of life history variants. Selective harvest, hatchery operations (e.g., broodstock selection, straying, domestication), dams that block migration or kill migrants, water withdrawals for irrigation, or other consumptive water use and land use practices that destroy the riparian zone of streams also alter the fitness of life history variants.

Life history diversity is a readily observable feature of salmon populations which is related to fitness and productivity of the stock. Life history then, should be an important focus of management and restoration programs (Weavers 1993). However, life history has generally been treated as a generic or invariant trait of the species or race. Recent studies of intrapopulation life history diversity (Lestelle et al. 1993; Gharrett and Smoker 1993a; Carl and Healey 1984; Reimers 1973; Schluchter and Lichatowich 1977) are exceptions. Where intrapopulation life history diversity has been looked for and evaluated it has generally been found to have management application.

Chinook Salmon Life His-

Healey (1991) structured the life histories of chinook salmon around two patterns of freshwater residence during the juvenile life stage. The two patterns were first described by Gilbert (1912) who labelled them ocean and stream types. Ocean type fish exhibit a short freshwater residence, usually migrating to sea within six months of emergence. Stream type fish migrate to sea in the spring of their second year. In some northern stocks, juvenile chinook may remain in freshwater for two or more years. Stream type life histories are found in rivers north of 56°N and in populations that spawn in the upper reaches of rivers that penetrate long distances inland such as the Fraser and Columbia rivers. Between 56°N and the Columbia River both life history patterns are present. South of the Columbia River the ocean type life history dominates (Healey 1991; Taylor 1991) (Figure 12). Healey (1991) associated the stream type life history variant with adult spawning migrations in the spring and summer and the ocean type variant with adult spawning runs in summer and winter. This generalization breaks down, however, on the California, Oregon and Washington coasts where the spring chinook runs are often comprised of a significant proportion of fish with ocean type life histories. For example, in the Rogue River, 95 percent of the adult spring chinook exhibit the ocean type life history pattern (Nicholas and Hankin 1989).

Intrapopulation life history patterns observed in chinook salmon (e.g., Reimers 1973; Schluchter and Lichatowich 1977; Carl and Healey 1984; Nicholas and Hankin 1989) and the geographic distribution of those life histories (e.g., Taylor 1990a; Healey 1991) might be interpreted as evidence for adaptive developmental plasticity. Even though evidence for a genetic basis for local life history traits is accumulating (e.g., Gharrett and Smoker 1993a; Carl and Healey 1984), overall,

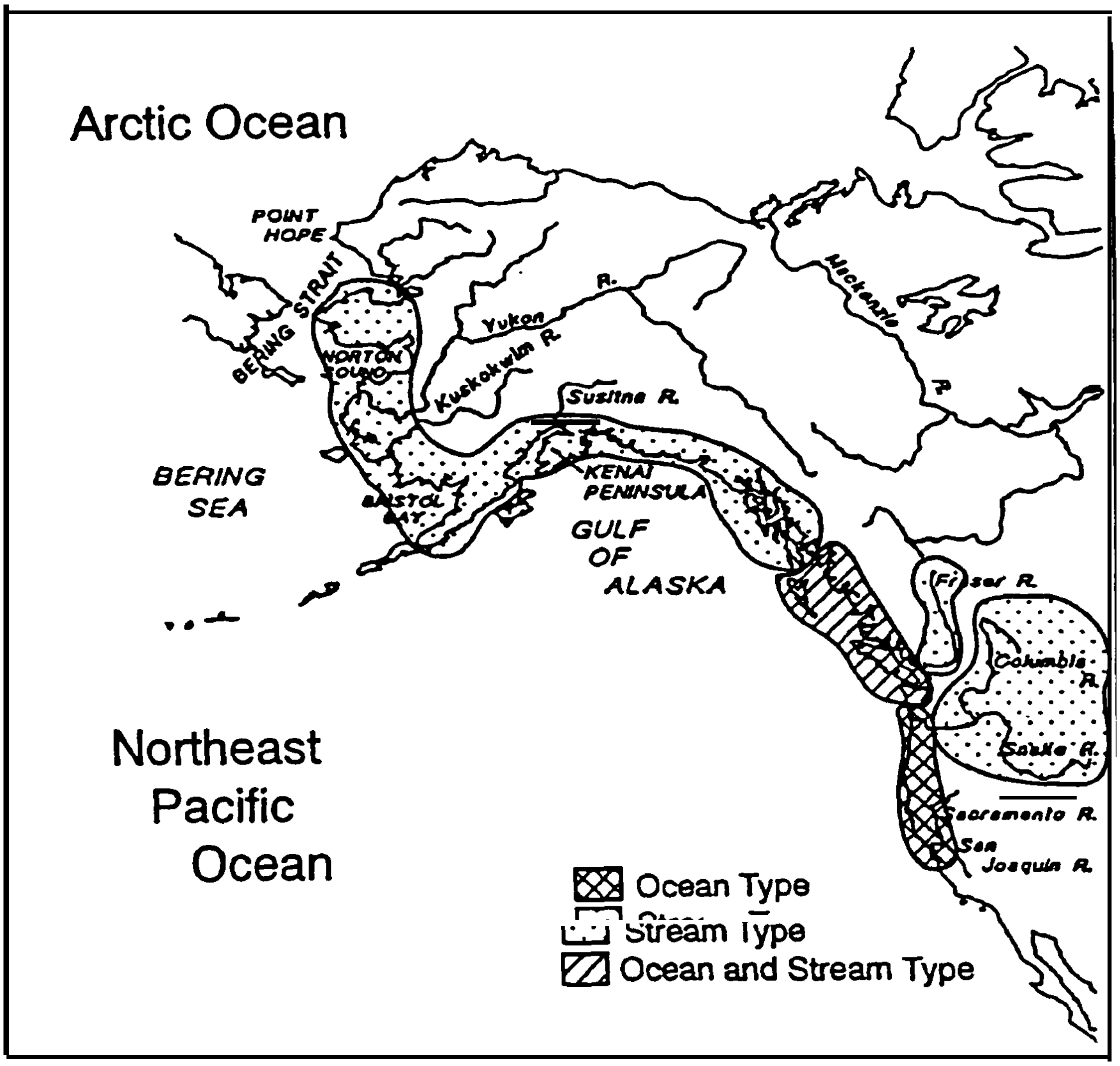


Figure 12. **Distribution of stream and ocean type life histories in chinook salmon. (Based on data from Taylor 1990a)**

the evidence that life history traits of local populations are adaptive is largely circumstantial (Taylor 1991).

Life history traits may represent developmental conversion or environmental modulation (Smith-Gill 1883). Life history is the product of developmental conversion if the salmon's possible developmental pathways are genetically programmed to respond to environmental cues. Life history traits are environmentally modulated when they are simply a passive response to environmental variability.

Based on a review of the geographic distribution of the stream and ocean type life history patterns in relation to environmental factors, Taylor (1990a) concluded that variability in the age at seaward migration in chinook salmon is a response to the environment. Stream or ocean type life history is a response to variability in growth opportunity (temperature and photoperiod) and distance from the sea. He concluded life history variability represents in part environmental modulation of the timing of smolting, however, he conceded that this mechanism might be constrained by selection for size at migration.

Support for Taylor's (1990a) hypothesis regarding environmental modulation of life history type through growth opportunity comes from a study of juvenile chinook salmon in the Situk River, Alaska (Johnson et al.1992). Even though the Situk River is above 56°N, the theoretical northern limit of the ocean type life history, the dominant juvenile life history was the ocean type — most juveniles migrated to sea by November of their first year. Growth opportunity might have been enhanced by warm river temperatures due to the influence of Situk Lake.

Taylor's (1990a) conclusion regarding the environmental modulation of chinook salmon life histories was challenged following a series of experiments on the genetic control of the expression of stream and ocean type life histories in chinook salmon (Clarke et al. 1992). The experiments demonstrated developmental conversion in chinook salmon populations that normally exhibit the stream type life history. When juveniles from a stream type population, were exposed to short day length at first feeding followed by exposure to long day length, they grew rapidly and developed seawater tolerance similar to the ocean type pattern. When juveniles from the same population were exposed to long day length at first feeding, their growth was slower and consistent with stream type life history. Juvenile chinook salmon from a population that normally exhibited the ocean type life history did not show this developmental conversion — they grew rapidly regardless of day length at first feeding. Fry from crosses of both reciprocal stream type-ocean type hybrid groups displayed the ocean type pattern. This suggests that ocean type life history is dominant and that photoperiod responsiveness may be under Mendelian genetic control (Clarke et al. 1992).

In another controlled laboratory experiment, juvenile chinook salmon reared under common environments in the laboratory, exhibited phenotypic variability in aggression, growth and positive rheotaxis among several populations (Taylor 1990b). The differences between populations were functionally consistent with each population's normal freshwater life history (stream or ocean type). Based on this observation, Taylor (1990b) argued that the observed phenotypic variability represented adaptive divergence within the species. Increased fitness of functionally related life history traits could have resulted in selection for those traits.

As with many phenotypic traits, juvenile migration is probably under both genetic and environmental control.

Within a given watershed and population of chinook salmon the distinction between stream and ocean type life history patterns blurs into a diversity of more complex patterns. Reimers (1973) identified five life history patterns in Sixes River fall chinook based on timing of downstream migration, the extent of estuarine rearing and timing of ocean entrance. Using criteria similar to Reimers (1973), Schluchter and Lichatowich (1977) identified eight life history patterns in spring chinook salmon from the Rogue River. Carl and Healey (1984) identified three life history patterns for juvenile fall chinook salmon in the Nanaimo River. Genetic differences in juveniles exhibiting the different life histories were demonstrated (Carl and Healey 1984). Stream type life histories may show variation in migration and rearing distribution within tributaries and between tributaries and the mainstems of larger rivers (e.g., Lindsay et al. 1986 and 1989; Fast et al. 1991; Burck 1993).

From the foregoing discussion of chinook salmon life histories the following salient points can be summarized:

- **Juvenile life history patterns are probably neither entirely determined by environmental modulation or developmental conversion. Life histories probably result from a combination of the two.**

- **The ocean type life history pattern is dominant.**

- **Stream type life history is determined in part by photoperiod at emergence and stream temperatures.**

- **Under healthy habitat conditions, a population of juvenile chinook will exhibit several variations of the stream and/or ocean type life histories.**

TEMPLATE DESCRIPTION

General Description of Abundance, Habitat and Life History of Chinook Salmon in the Columbia River

Predevelopment Abundance of Salmon

The NPPC (1986) used several different approaches to estimate predevelopment abundance of Pacific salmon in the Columbia River which yielded a range of annual run sizes of 8-35 million salmon and steelhead. Following an assessment of the various methods, the NPPC narrowed the range to 1 O-l 6 million fish (NPPC 1986 p. 14). Included in that total were 4.7 to 9.2 million chinook salmon (NPPC 1986, Table 6). Those point estimates of abundance give an indication of the size of the predevelopment runs into the Columbia River but not the natural variation in abundance. Continuous estimates of abundance through the early decades of the commercial salmon fishery are not available. However, the size of the commercial harvest can be used as an index of the long-term trend in abundance.

Commercial Harvest

The commercial harvest and export of salted salmon began in the 1820s and grew modestly to 2,000 barrels by the early 1860s. Intensive fisheries did not begin until cannery technology reached the Columbia River in 1866 (Craig and Hacker 1940). After 1866, the catch of salmon and the amount of fishing gear employed in obtaining that catch increased rapidly (Figure 13). The harvest of chinook salmon peaked in 1883 at 42,799,000 lbs. (Beiningen 1976). The catch declined from that peak and entered a period of sustained harvest fluctuating around an average catch of about 25 million pounds for the next 30 years. About 1920, the catch went into a decline that continued through to the end of the template period (Figure 13).

In the final decades of the 19th Century and the early decades of the 20th Century, the salmon canning industry shifted locations and species to maintain production. The industry shifted northward as the salmon in the southern rivers were depleted (DeLoach 1939). In addition, species such as chum, pink and coho salmon which were considered “inferior” were canned in increasing numbers when the preferred chinook and sockeye salmon, failed to satisfy demand (DeLoach 1939). Chinook salmon always brought the highest price (DeLoach 1939) and the chinook salmon that entered the river in spring and early summer were of highest quality (Hume 1893; Cobb 1930; and Craig and Hacker 1940).

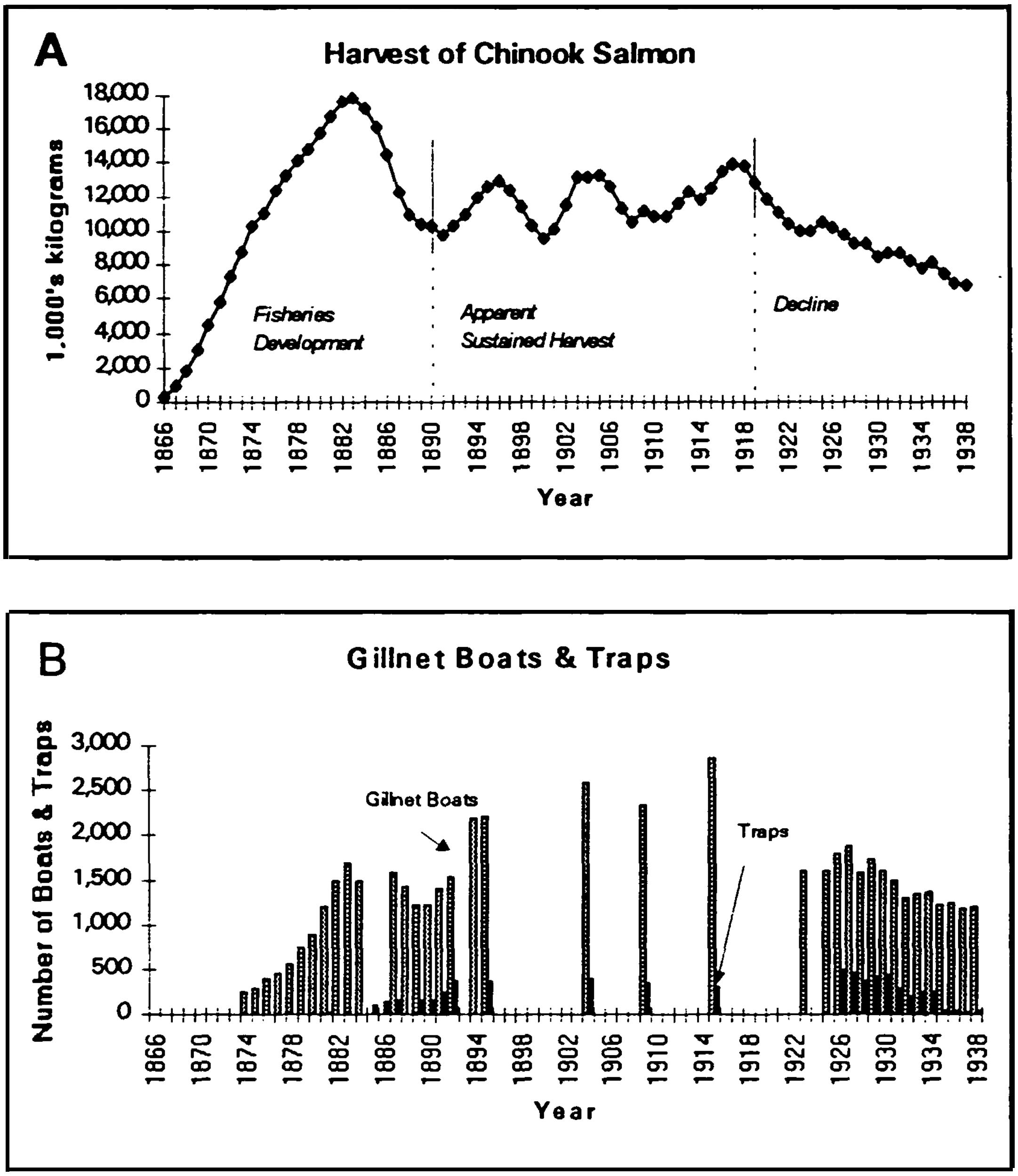


Figure 13. Trend in chinook salmon abundance in the Columbia River during the template period. (A) is the five year running average of chinook salmon harvest. (B) describes the growth in the number of gillnet boats and traps employed in the fishery. (Data from A - Beiningen 1976 and B - Smith 1979).

The harvest of chinook salmon in the Columbia River underwent importaht qualitative changes which are not evident from an examination of the harvest data shown in Figure 13. The canneries prized the spring and early summer run of chinook salmon and targeted those fish during the early years of the fishery. In 1892, 95 percent of the harvest was taken from the spring and summer run. By 1912, the spring/summer run fish in the harvest dropped to 75 percent as more fall chinook were harvested, and by 1920, fall chinook salmon made up 50 percent of the catch (Smith 1979) (Figure 14). Between 1892 and 1920, the fishery for Columbia River chinook salmon appeared to be in a period of relative stability, however, underneath the catch statistics a major life history shift was taking place (Figures 14 and 15). The spring/summer run was rapidly declining. Production quantity was maintained through a qualitative shift in the fishery to fall chinook salmon. Fall chinook were not as desirable for canning because of their lower oil content and color (Smith 1979). Because of the shift in the fishery from spring/summer to fall chinook, Craig and Hacker (1940) suggested that a real decline in chinook salmon abundance in the Columbia River began in 1911. They attributed the decline to overharvest and habitat degradation.

Early Habitat Degradation in the Columbia Basin

One of the important causes of habitat degradation in the study area (Cascade rainshadow) in the late 19th Century and early part of this century was irrigated agriculture. Irrigation impacted anadromous salmonids in three ways: the loss of migrating juveniles in unscreened irrigation ditches, the dewatering of tributaries which eliminated habitat and blocked migration of juvenile and adult salmon, and the construction of dams to divert irrigation water into ditches which also blocked migration. The problems stemming from the construction of irrigation systems and power dams in the tributaries were serious and they were mentioned frequently in the early reports of salmon management institutions. As early as 1890, the Oregon State Board of Fish Commissioners reported the loss of juvenile salmon in irrigation ditches and requested legislation to prevent such losses (Oregon State Board of Fish Commissioners 1890 and 1892). The persistence of salmon losses in unscreened irrigation ditches was described by the Oregon State Fish and Game Protector in his report to the legislature in 1896. Again, in 1901, the annual report for the Oregon Department of Fisheries contained this statement:

> *"Another and more serious reason for salmon not entering many of the streams of eastern Oregon and Idaho in such large numbers as they did years ago, must be attributed to the settler. This part of the country being dry, requiring irrigation during the summer months, dams have been built on nearly all the small streams, water being taken from them and carried in ditches for miles for this purpose, thus destroying much of the best spawning grounds."*

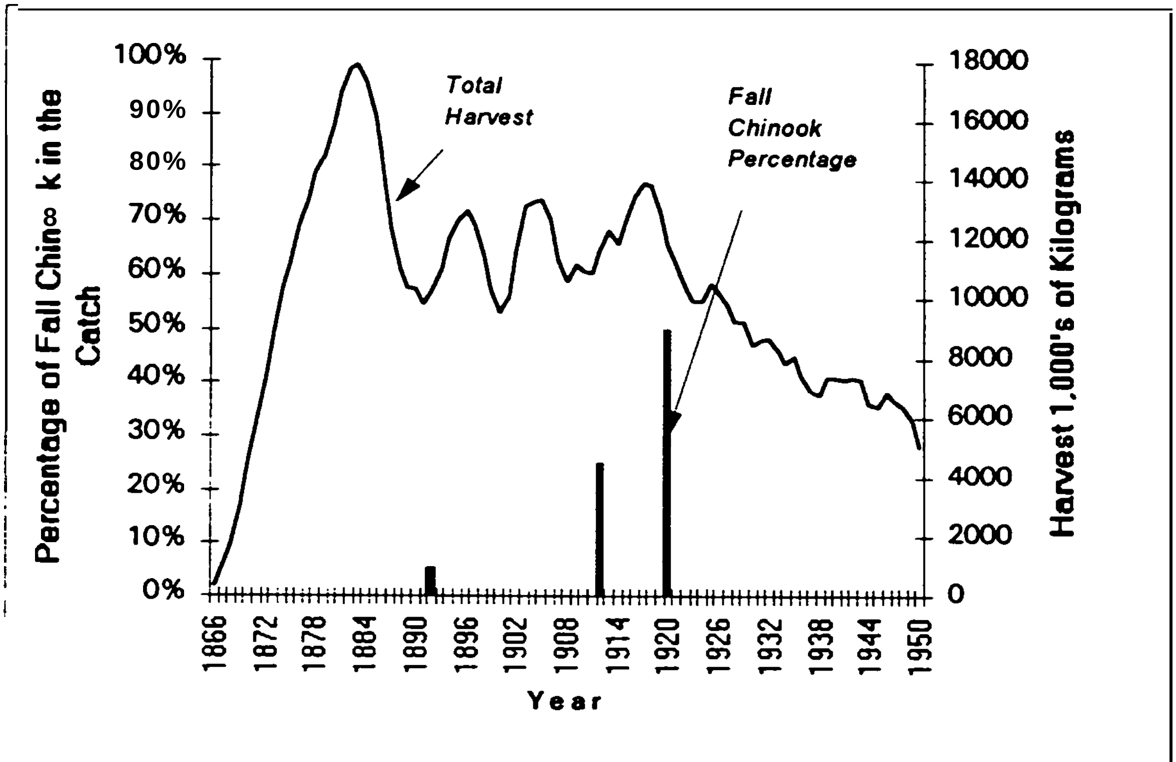


Figure 14. Five year moving average of chinook salmon harvest in the Columbia River and the percentage of the catch made up of fall chinook in 1892, 1912 and 1920. (From Beiningen 1976 and Smith 1979)

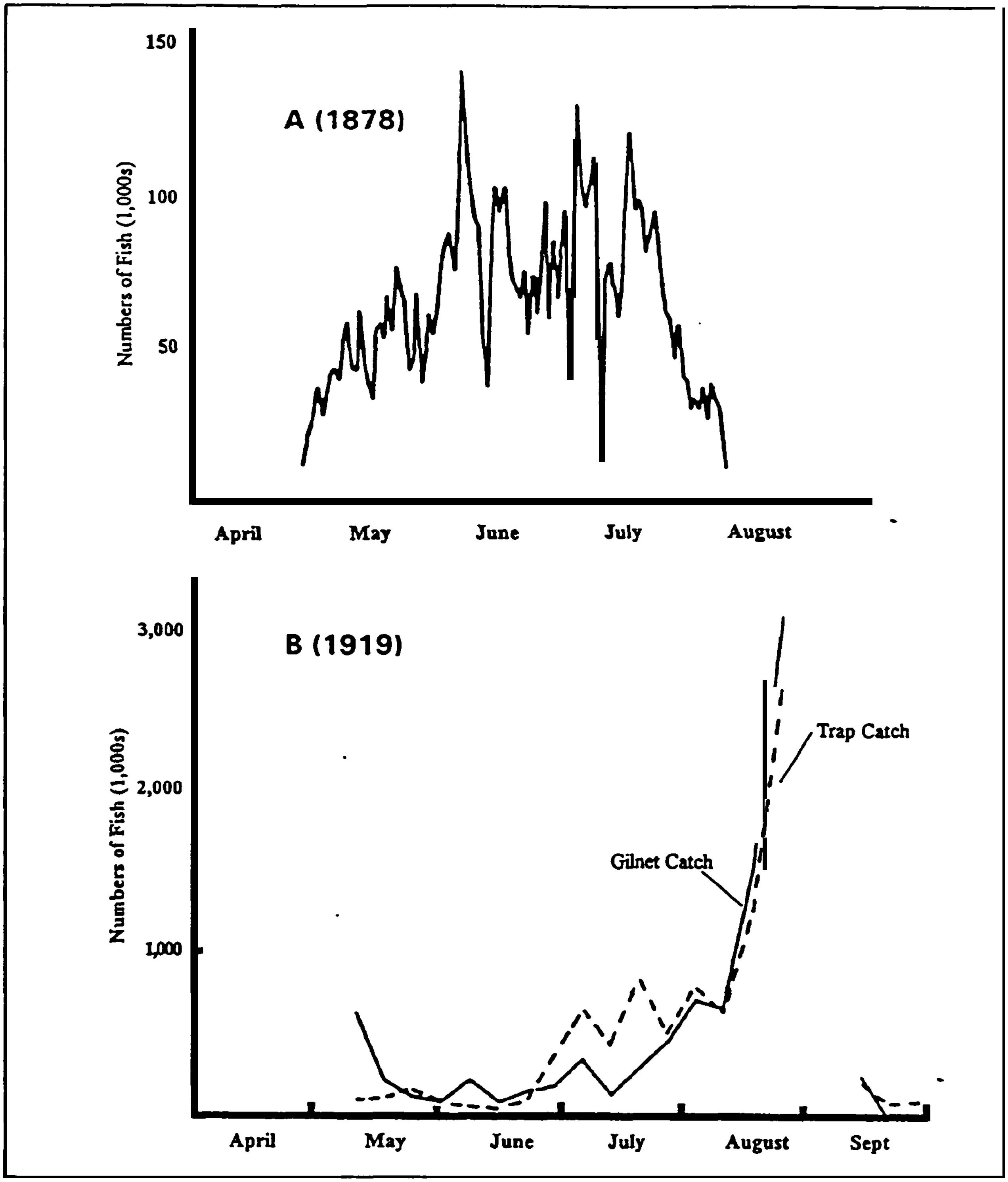


Figure 15. Comparison of the seasonal distribution of the chinook harvest in the Columbia River in 1878 (A) and 1919 (B). (From Whitney and White 1984)

The Washington State Department of Fisheries and Game (1904) also identified irrigation withdrawals as a major problem affecting young salmon in the eastern part of that state.

Irrigation was just one of many activities that contributed to the degradation of salmon habitat. Gold mining, cattle and sheep grazing, timber harvest, dams for hydropower all contributed to the decline of salmon habitat. The growth and development of all these activities are summarized in NPPC (1986).

The total habitat loss and degradation in the early decades of this century was extensive. The 1932 biennial report of the Oregon Fish Commission (OFC) describes a color map of the Columbia Basin prepared by the Commission staff over a 15 year period. The map apparently showed that 50 percent of the most productive spawning and rearing areas within the Columbia Basin had been lost due to dams for irrigation and power (OFC 1933). While the intensity of the harvest probably contributed to the decline in spring and summer chinook prior to 1940, habitat degradation cannot escape being listed as a major contributor to that decline.

When they occur together, the effects of habitat degradation and overharvest are not independent. As habitat is degraded, harvestable surplus declines which intensifies the effect of poorly regulated and intensive fisheries. A fishery operating at intensive but sustainable levels can quickly shift to overharvest when habitat degradation is allowed to occur.

Life Histories of Columbia River Chinook Salmon

As mentioned earlier, the distribution of the catch among the spring, summer and fall races of chinook salmon shows a qualitative shift in life history in the early decades of the commercial fishery (Figures 14 and 15). The harvest of spring and summer chinook declined and the catch of fall run fish increased. In addition to the shift in relative abundance of different races of chinook salmon, the size and age structure of chinook salmon were also declining as early as the 1920's (Ricker 1980).

The timing of juvenile migration to the sea is an important life history trait that shows less annual variability than, for example, adult abundance. The relatively low within-population variability in the seasonal migration peaks might indicate that timing has high survival value (Lichatowich and Cramer 1979). Migration timing may be tuned to flow conditions in the subbasin and mainstem that are favorable to safe transport downstream. Migration may also be timed to ensure that juveniles arrive in the estuary or ocean when food is abundant.

Juvenile chinook salmon were collected by beach seine in the lower Columbia River in 1914, 1915 and 1916. Although interpretation of these data in terms of juvenile migration has several problems (Rich 1920), it is the only information available. The data suggest that the migration of ocean type juveniles extended over a large part of the spring, summer and fall (Figure 16). Rich (1920) suggested that the extended period of juvenile presence represented movement of successive populations of juveniles from different tributaries. He speculated that the late migrating fish were from tributaries increasingly further up stream. Yearling chinook were a small part of the total juveniles captured.

The age distribution of returning adults and their juvenile life histories (ocean or stream type) were determined in the early decades of this century for the Columbia River (Rich 1925) and for the Sacramento and Klamath rivers (Snyder 1931) (Figures 17 and 18). Unfortunately, the life history data for spring/summer chinook in the Columbia River may not reflect the predevelopment and pre-

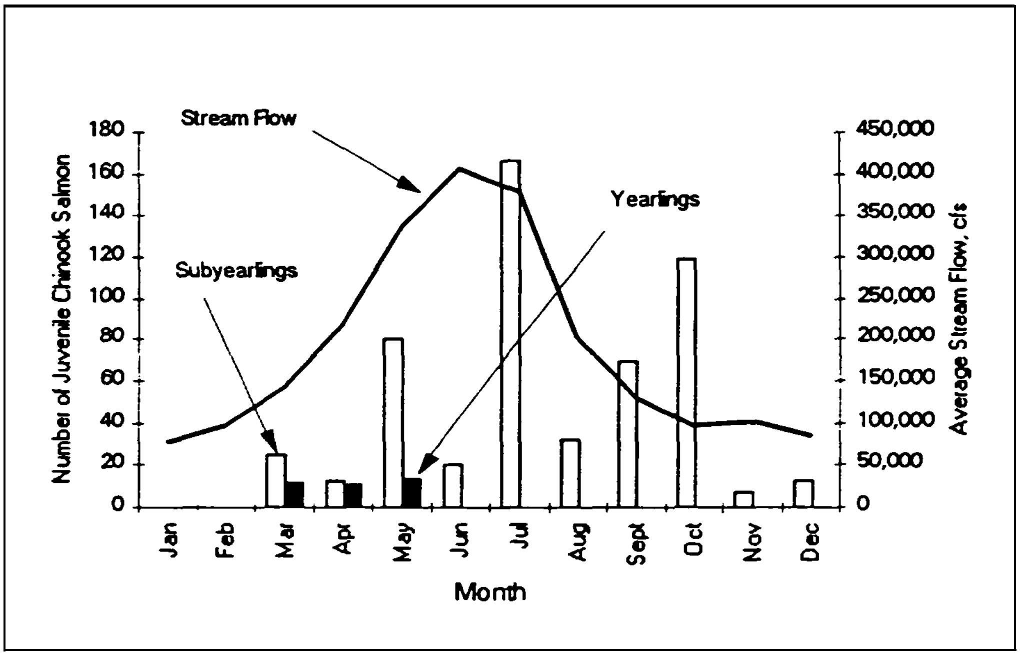
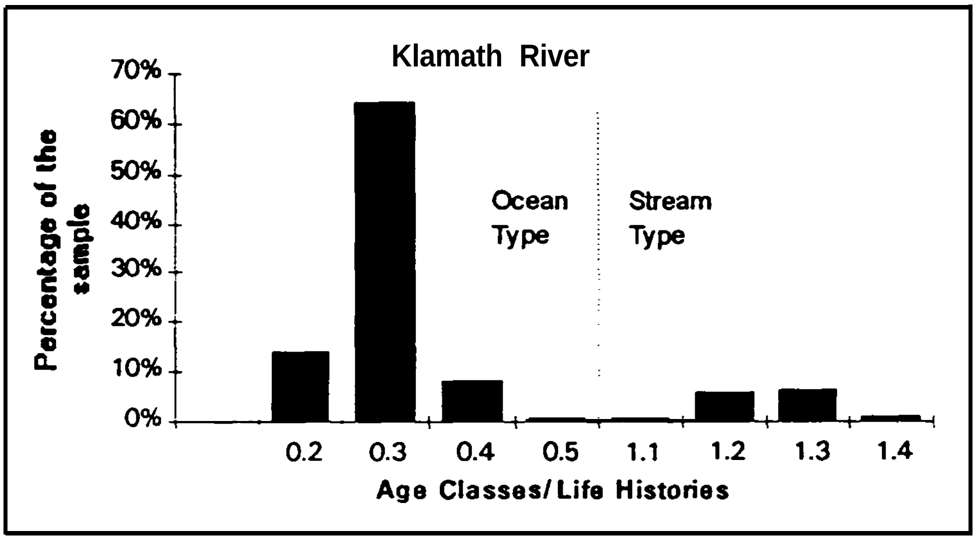


Figure 16. Average monthly catch of juvenile chinook salmon in the lower Columbia River 1914 to 1916. Average monthly stream flow at The Dalles for 1916. (Salmon data from Rich 1920, Flow data from Hydrosphere, Inc. 1990)

commercial harvest conditions. The juvenile life histories of the Columbia River chinook salmon were obtained in 1919-l 923 or after the spring/summer chinook runs had already experienced significant declines in abundance (Figures 14 and 15).



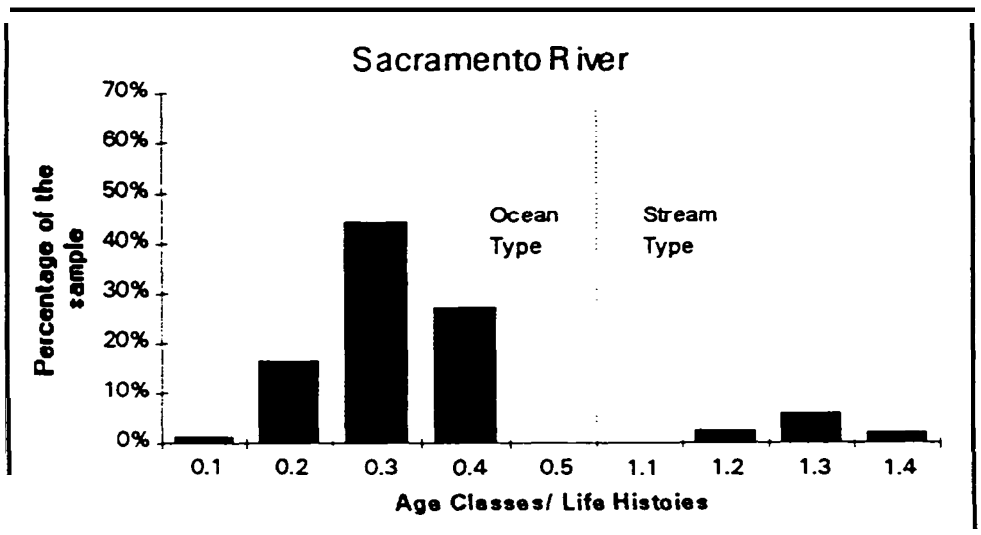


Figure 17. Age distribution of adults and juvenile life histories of chinook salmon in the Sacramento River for 1919 and 1921 and the Klamath River for 1919, 1920 and 1923. See text for explanation of age class/life history designation. (From Snyder 1931)

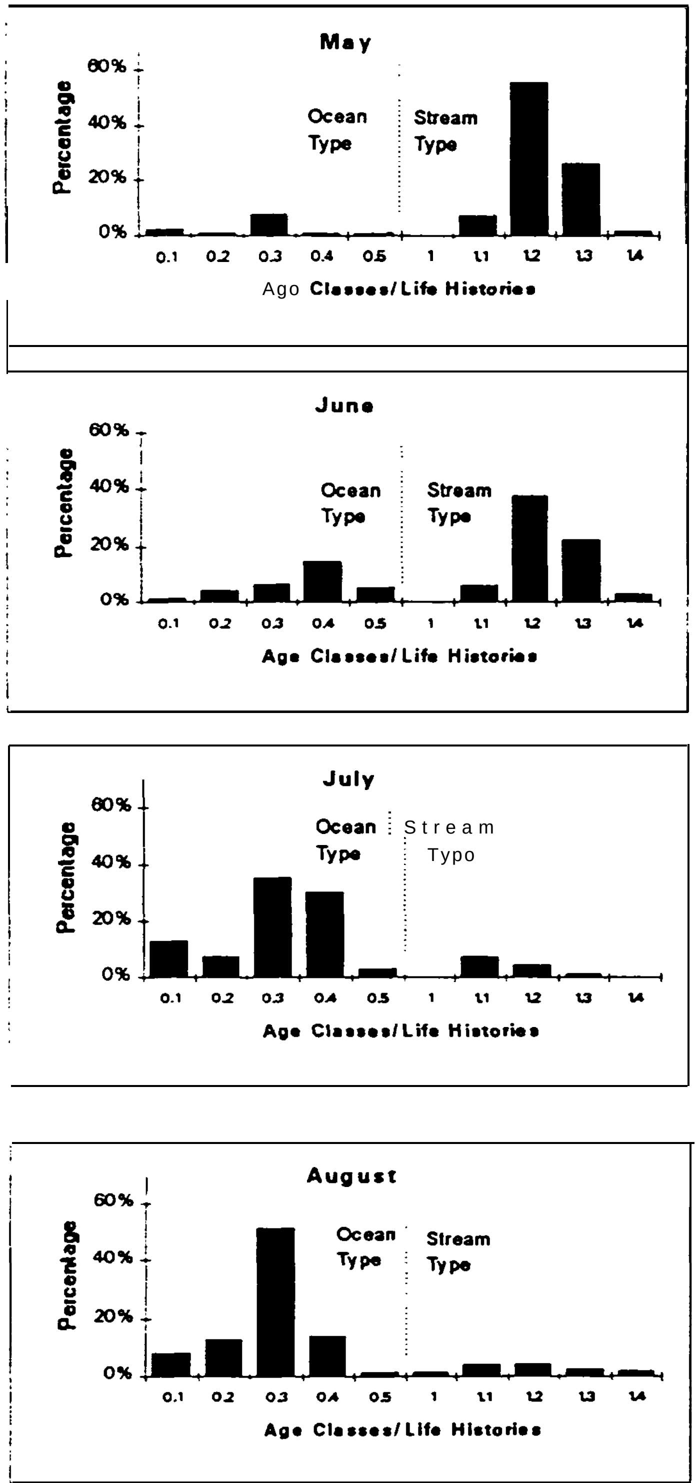


Figure 18. **Average monthly age distribution and juvenile life histories of adult chinook salmon collected in the lower Columbia River May through August in 7919. See text for explanation of age class/life history designation. (From Rich 1925)**

Age and life history designation in Figures 17 and 18 follow this method: The number of winters spent in freshwater, excluding egg incubation, are designated by the numeral to the left of the period. The number to the right of the period indicates the number of winters spent in saltwater. Total age is the sum of the two numbers plus 1. Ocean type life history is designated by a 0 to the left of the period. Age classes and juvenile life histories (ocean and stream type) were determined from an analysis of scales removed from adult fish.

The ocean type life history was important in the Sacramento and Klamath rivers. The juvenile life histories cannot be separated by race because data from those two rivers are composite samples including spring/summer/fall run fish. However, of 35 fish sampled from the spring run in the Klamath River, 29 exhibited the ocean type life history pattern (Snyder 1931 p. 23).

In the Columbia River, the juvenile life histories of returning adults changed through the migratory season (Figure 18). Monthly averages of the histories are shown in Figure 18. In daily samples, the ocean type life history pattern was observed on as many as 38 percent of the scales collected on May 27 and 63 percent of the fish sampled on June 24-25 respectively (Table 1). However, the stream type life history dominated in May and June and ocean type life history dominated in July and August. This led to the conclusion that spring run fish have the stream type life history and fall run fish have the ocean type life history pattern (Rich 1925) which has persisted until the present (Healey 1991).

In the Columbia and Klamath rivers, chinook salmon migrated downstream to sea throughout the year (Rich 1920), so the distinction between ocean type and stream type life histories was not always clear to early workers (Rich and Holmes 1928; Synder 1931). In fact, the majority of the chinook salmon scales analyzed showed neither a typical stream or ocean type life history pattern. The fish spent part of their first year in freshwater and part in saltwater (Rich and Holmes 1928). Because of this uncertainty, some late migrating, ocean type fish might have been classified as stream type. This is particularly true for the fish sampled in May and June (Table 1) because conventional wisdom held that the spring run fish had the stream type life history.

It must be emphasized that the data in Table 1 and Figure 18 were collected in the Columbia River after the spring/summer run was in significant decline (Figure 15). Factors creating that decline — habitat destruction in particular — may have selectively reduced specific life history patterns and distorted the importance of the remaining life histories.

Table 1. Percentage of ocean and stream type life histories observed on scales of adult chinook salmon returning to the Columbia River in 1919. (Data from Rich 1925)

Month	Sample Date	Percentage Ocean Type	Percentage Stream Type
May	10	2.4	97.6
	13	10.7	89.3
	16		100.0
	17-18	9.3	90.7
	27	38.7	61.3
	30-31	6.0	94.0
June	10	35.0	65.0
	16	9.1	90.9
	17	17.3	82.7
	24-25	63.0	37.1
July	3	88.3	11.8
	7	85.6	14.1
	16	77.6	22.4
	28	98.0	2.0
August	5	75.0	25.0
	6	92.6	7.4
	22	92.6	7.4
September	12	87.4	12.7

Yakima River

Abundance. Robison (1957) divided his estimates of the abundance of salmon in the Yakima River into four periods: Prior to 1847, 1875-l 905, 1905-l 930 and 1930-l 949.

- Prior to 1847. The Native American harvest of salmon in the Yakima River was estimated to be 160,000 adult fish. Assuming the actual run to the river was three times the catch, the total run of salmon would have been about 500,000 fish (Robison 1957). The predevelopment abundance of Pacific salmon was also back calculated from the total area of spawning habitat and the area needed by a single pair of spawning chinook salmon. Dividing the total area by the area occupied by a single pair and assuming full seeding led to an estimate of 500,000 salmon. Species were not differentiated.

- 1875-l 905. Rapid development in the Yakima Basin including intensive development of irrigation, logging, hydraulic mining, over-harvest and neglect by management agencies contributed to a drastic decline in abundance of salmon (Robison 1957). During this period, the catch declined to about 20,000 salmon annually. Another estimate put total abundance by the end of the century at about 50,000 salmon (Davidson 1965).

- 1 905-l 930. After 1905, the catch declined annually until 1930 when it amounted to about 1,000 spring chinook. The major salmon fishery on sockeye salmon was eliminated by 1905 (Robison 1957).

- 1930-1949. The catch ranged from 1,000 to 1,500 spring chinook salmon.

Smoker (1956 reported in Fast et al. 1991) estimated the historic size of the Yakima River spring chinook population at 250,000. CTYIN et al. (1990) reviewed historic abundance of spring chinook in the Yakima Basin and concluded that 90% of the run was lost between 1850 and 1900.

The early estimates of abundance of chinook salmon in the Yakima River were obtained through indirect methods so the specific numerical value must be used with caution. However, a reasonable inference is that the run of chinook salmon was large, in the range of 100,000 to 300,000 fish. The chinook population underwent significant decline before 1900.

Habitat. The extent of early habitat degradation in the Yakima River is difficult to establish with any accuracy, however, there is evidence to suggest that the quality of salmon habitat declined significantly by the later decades of the 19th century and continued to decline through the early decades of this century. The timing of habitat destruction is consistent with the timing of the decline in abundance of chinook salmon. Salmon habitat was altered by logging, mining and grazing, however, irrigation probably had the biggest impact on salmon production and productivity.

The first irrigation ditch in the Yakima Basin was constructed in 1853, and the first ditch of large size was finished in 1875 (Kuhler 1940). Construction of irrigation ditches continued through the 1880s. Passage of legislation favorable to the development of irrigation projects enhanced construction activity in the decade 1890 to 1900 (Kuhler 1940). Between 1905 and 1930 the acreage under irrigation increased from 121,000 to 203,000 (Robison 1957) and by 1947, 354,877 acres were being irrigated (Davidson 1965). It was not until 1930 that efforts were initiated to protect salmon from unscreened irrigation ditches (Davidson 1965).

Irrigation had its biggest effect on salmon habitat in the middle and lower Yakima River. The loss of salmon fry in irrigation ditches, the dewatering of streams and the migration blockage have all been attributed to irrigation in the closing decades of the 19th Century and the early decades of the 20th Century. However, with one exception, we found no published studies that quantified the impact of the early, unscreened irrigation diversions on salmon.

In 1920, Dennis Winn, the field superintendent for hatchery work on the Pacific Coast for the U. S. Bureau of Fisheries, was directed to investigate the effects of irrigation on salmon and steelhead in the Yakima River. Although Mr. Winn made his inspection trip during the winter after the ditches had been shut down, and few juvenile fish were migrating, he still found evidence of significant numbers of salmon in the ditches (*Pacific Fishermen* 1920). In his report, Winn also discussed a study that attempted to quantify the loss of juvenile salmon in unscreened irrigation ditches in the Yakima River. The study was conducted by biologist Frank Bryant in July, 1916. Bryant subsampled a total of 200 acres of irrigated land after it had been watered — the fishes stranded on the 200 acres were counted. He found 20 fish/acre or a total of 4,000 fish in the 200 acres of which 90% were migrating salmon. Extrapolated to the entire basin, Bryant estimated 4,500,000

migrating salmon were lost with each watering *Pacific Fisherman* 1920). The extrapolated estimate of total losses needs to be viewed with caution; however, it does indicate a problem of significant proportions.

The location of major irrigation diversions in the Yakima River (Figure 19) suggest that the progeny of chinook salmon that spawned in the middle and upper reaches of the Yakima River were most vulnerable to unscreened diversions. Spring and summer chinook spawned in the middle and upper basin. Bryant's study was conducted in fields irrigated by the Hubbard Ditch which was located just below the confluence of the Yakima and Naches Rivers. The mortalities counted by Bryant would have been juvenile spring or summer chinook.

In the upper Yakima River, the major impacts on salmon habitat came from grazing and fires. Many of the fires were set by sheepmen to improve the range (Smith 1993). The extent of the burns near the turn of the century caused the U. S. Geological Survey to conclude that the watershed had been degraded to the point of possibly threatening the water supply for irrigation in the basin (Plummer 1902). The number of sheep in the basin grew rapidly prior to 1900 — 5,000 in 1879 to 16,000 by 1889 and 261,000 by 1899. After the turn of the century large scale grazing declined (Kuhler 1940).

It's clear that habitat degradation was a major factor in the decline of spring and summer chinook salmon in the Yakima Basin. Habitat degradation was severe enough in the later decades of the 18th Century to suggest that it contributed to the early decline in the commercial fishery for spring and summer chinook salmon discussed earlier in this report.

Life History. Life history of juvenile chinook salmon in the Yakima River can be inferred from the records of salmon observed in irrigation ditches. Those data were collected by a Washington Department of Fisheries employee, Ernie Brannon, in 1929 and 1930 and recorded in his work diary (Brannon 1929 and 1930). In some cases, Brannon made visual estimates of the number and species of fish in an irrigation ditch. In other cases, he captured the fish and counted them.

Unfortunately, the data do not extend over an entire year or migration season (Figure 20). In 1929, the irrigation ditches were sampled from mid-May to mid-June. The largest number of juvenile chinook salmon was observed on June 9 in the Sunnyside Canal. The 1930 data set, which did not begin until mid-July, shows large numbers of juvenile chinook salmon in the ditches in July. Fewer fish were observed in August and September. Movement of juvenile salmon into the irrigation ditches suggests they were actively migrating downstream. Juvenile

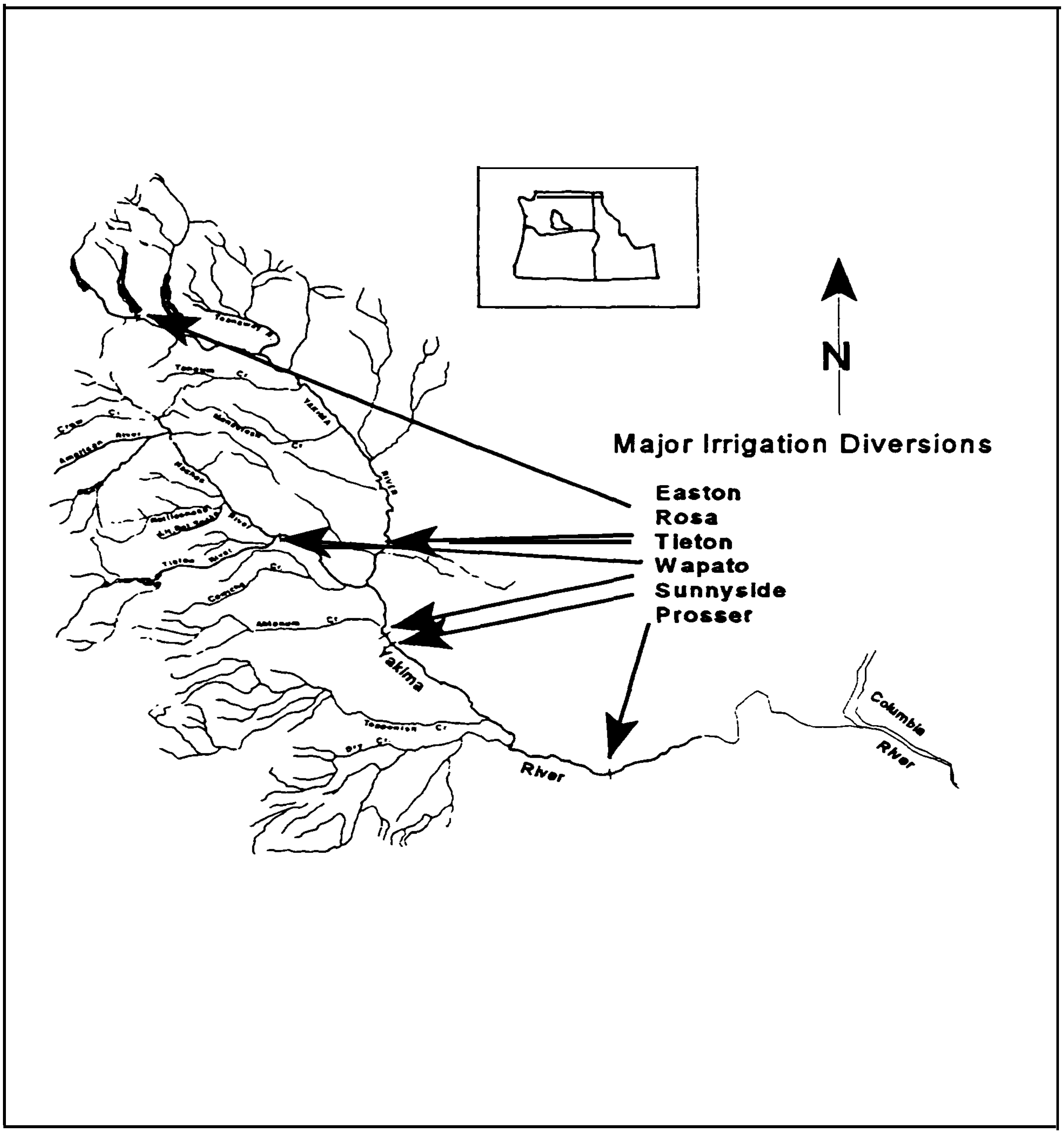
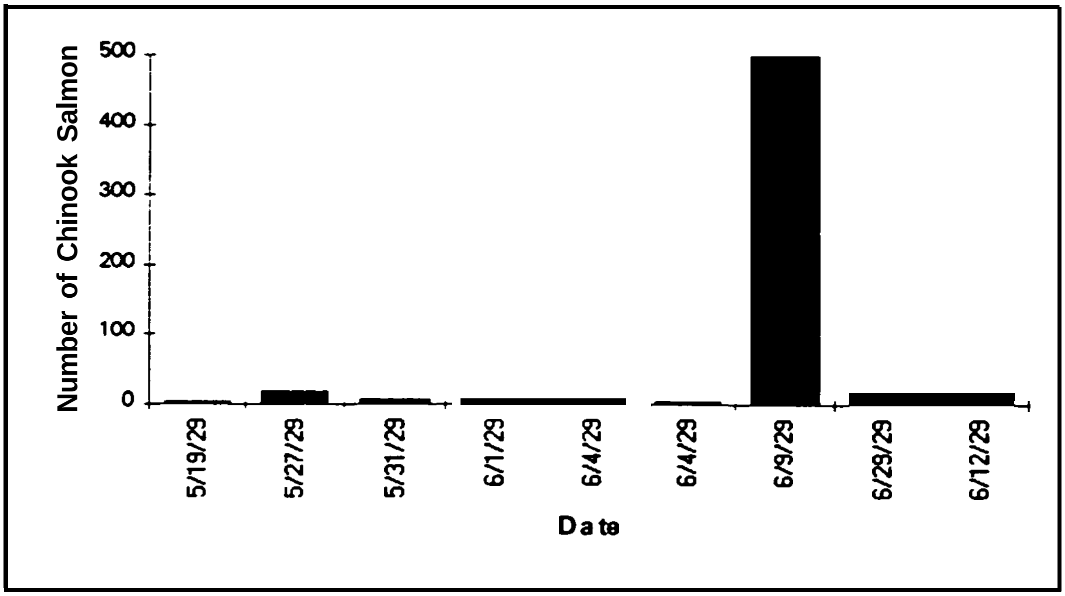


Figure 19. Location of major irrigation diversions in the Yakima Basin. (From U. S. Department of the Interior 1982)



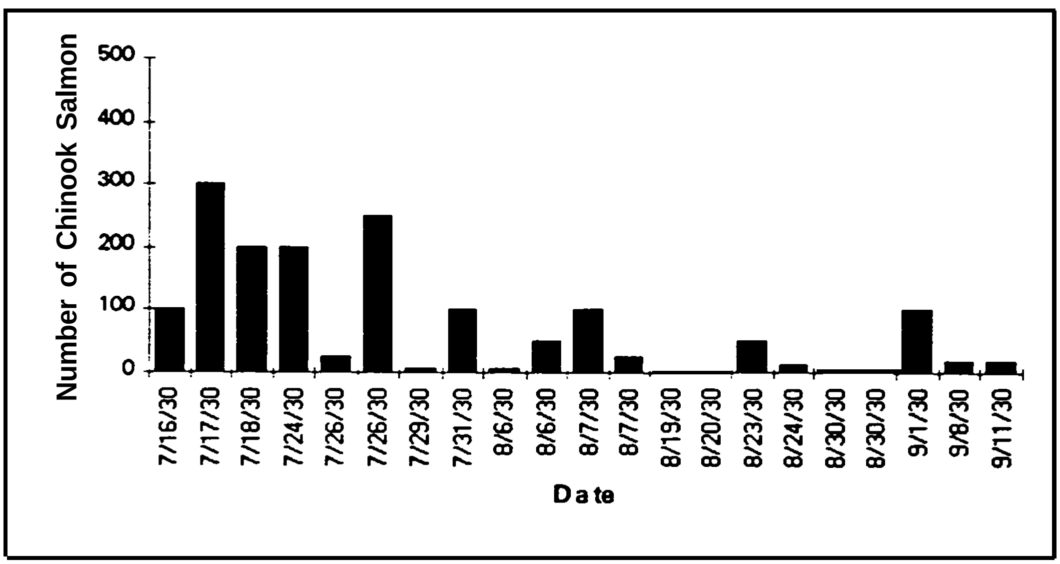


Figure 20. The number of juvenile chinook salmon observed in irrigation ditches in the Yakima Basin in 1929 and 1930. The data are combined observations from several ditches. (Data from Brannon 1929, 1930)

chinook salmon found in the ditches were 8 cm or larger which is consistent with the size of migrating smolts (Figure 21). Juvenile chinook salmon in Oregon's coastal basins may migrate to the sea as small as 7 cm. Based on an analysis of scales removed from adult chinook salmon, the size at ocean entrance of juveniles that survived to maturity was generally greater than 10 cm and between 10 cm and 14 cm (Nicholas and Hankin 1989). It is assumed that chinook salmon captured in irrigation ditches in July were subyearlings and they would grow at least another 2 cm in the mainstem Columbia River and estuary before entering the sea. Yearling fish would have left the system earlier in the year. Sizes obtained in July-September indicate high growth potential which also suggests an ocean type life history pattern.

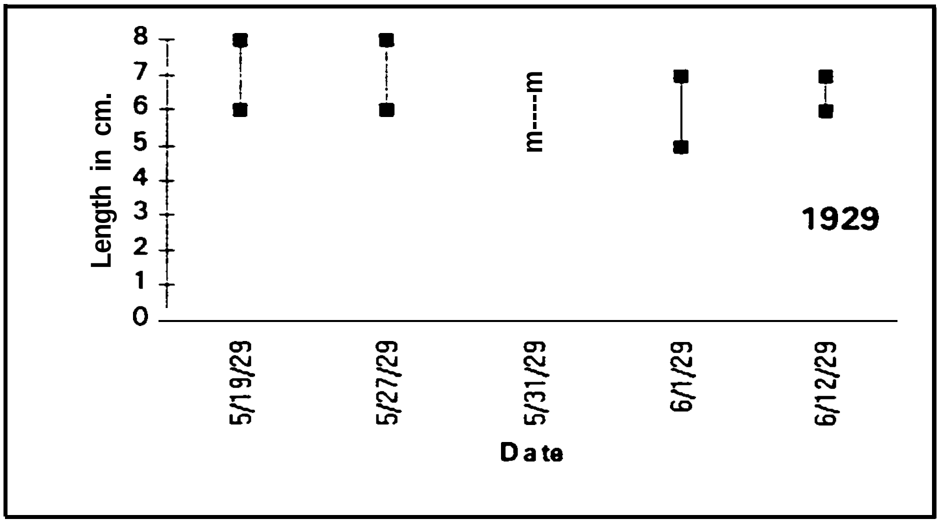
Bryant conducted his 1916 study of the losses of juvenile salmon in unscreened ditches in July because that was the peak of downstream movement at that time *(Pacific Fisherman* 1920). Haggart (1928) also observed a peak in migration in mid-summer. Even when the shortcomings of the data on life history are considered, it seems clear that juvenile spring/summer chinook were migrating in the Yakima River through the summer months. Juvenile chinook salmon migrating downstream during the summer would have suffered severe mortalities from unscreened irrigation ditches. In later years, the juvenile chinook salmon encountered lethal water temperatures in the lower river in July and August (see patient description).

Watson (personal communication; Bruce Watson, YIN, 1992) concluded that juvenile spring chinook salmon in the Yakima River historically exhibited six life history patterns (Table 2) including the ocean type. He based his conclusion regarding the ocean type life history on two pieces of historical information: 1) The predevelopment condition of the river channel and its dense riparian cover shaded the stream and that would have kept water temperatures cool; and 2) observations by Haggart (1928) that heavy outmigration of salmon in the Yakima River began in June, peaked in mid-July and continued through mid-September.

Tucannon River

Abundance. In 1989, the state fish commissioner reported that thousands of June migrating (spring run) salmon spawned in the Tucannon River in the 1880s. The run in 1898 consisted of a few dozen fish. (Washington State Fish Commissioner 1898).

Habitat and Life History. Historic information on habitat conditions and life history of chinook salmon was not found.



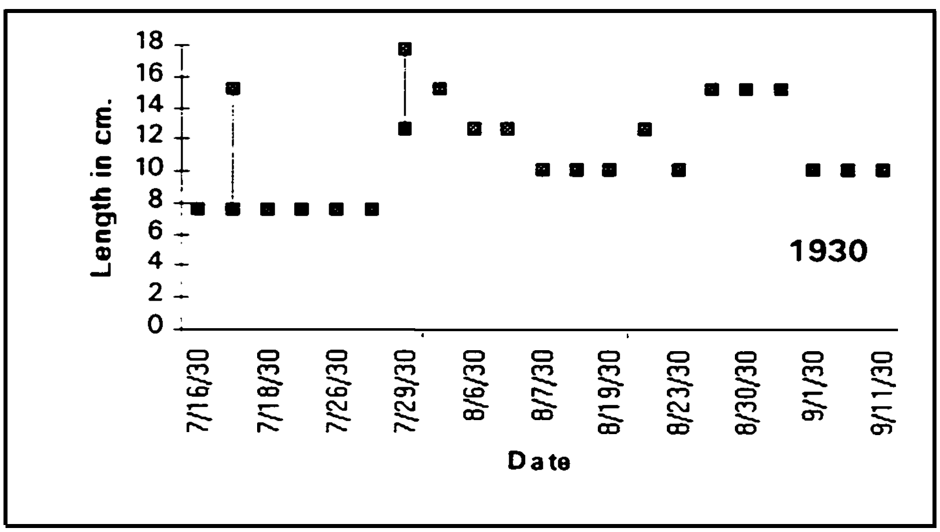


Figure 21. Size range of chinook salmon caught or viewed in irrigation ditches of the Yakima Basin in 1929-30. (From Brannon, 1929, 1930)

Table 2. Six life history patterns of spring chinook salmon that were historically present in the Yakima River. Pattern No. VI is the ocean type life history. (personal communication; Bruce Watson, YIN, 1992)

No.	Spawning Location	Summer Rearing Location (fry to parr)	Winter Rearing Location (pre-smolts)	Smolt Migration Route (subbasin)	Smolt Age
I	Upper tributaries	Upper tributaries	Upper tributaries	Entire drainage	I +
II	Upper tributaries	Upper mainstem	Upper mainstem	‘90% of drainage	I +
III	Upper mainstem	Upper mainstem	Upper mainstem	‘90% of drainage	I +
IV	Lower mainstem	Lower mainstem	Lower tributaries	< 50% of drainage	I +
V	All drainage units above lower mainstem	All drainage units above lower mainstem	Lower mainstem & associated “sloughs”	< 50% of drainage	I +
VI	All drainage units above lower mainstem	Lower mainstem	Not applicable	< 50% of drainage	o +

Umatilla River

Abundance. The largest run of chinook salmon in the Umatilla River within the memory of Euroamericans occurred in 1914. In that year, “thousands upon thousands of salmon from spring to fall” were harvested (Van Cleve and Ting 1960 p. 98). No more definitive estimate of historic abundance was found. Native spring and fall chinook and coho salmon were extirpated from the Umatilla River early in this century (CTUIR and ODFW 1990).

Habitat. The extinction of spring and fall chinook and coho salmon followed the construction of Three Mile Dam at RM 3 and the Hermiston Power and Light Dam at Rm 10 in 1914 and 1910 respectively (CTUIR and ODFW 1990). Similar to the Yakima River, irrigation was a major factor in the early degradation of salmon habitat in the Umatilla River. The earliest water right in the Umatilla Basin was granted in 1860 (CTUIR and ODFW 1990). Approximately 40 percent of the recognized water rights were granted prior to the enactment of the 1909 Water Code. More than 4,000 water rights totaling 4,600 cubic feet per second have been granted since then (CTUIR and ODFW 1990). Average stream flows at Umatilla in June, July and August are 121, 21.3 and 35.5 cfs respectively (CTUIR and ODFW 1990). Irrigation diversions dewatered the lower river during the salmon migration season (Van Cleve and Ting 1960).

Life H i s -. No specific observations of life history patterns were found. However, life history can be inferred from anecdotal information. In 1904, the *Pacific Fisherman* published a report from Pendleton, Oregon on a new device to be placed in streams to limit the destruction of juvenile salmon in irrigation ditches. In the same article, the *Pacific Fisherman* (1904 p. 21) stated:

> *"Another fruitful source of trouble is the drying up of streams near their mouth in the summer, due to the exhausting irrigation further up and evaporation. This prevents large numbers of fish which head to ward the Columbia River in September from ever getting to their destination. They come down as far as they can and are lost."*

Although the article did not identify the species, this observation is consistent with the subyearling migrant pattern in chinook salmon. It should be noted this problem was identified in 1904.

John Day Rivet

Abundance. As early as 1888, the Oregon State Board of Fish Commissioners (1888b p. 15) remarked that:

> *"The John Day River is quite a large stream, and in former years a large number of salmon ascended it, but within the last few years considerable mining has been done on its head waters, and this keeps the river muddy and the salmon have left it."* (underlining added)

Various interviews with local residents suggest that chinook salmon were more abundant in the 1920s than at present (personal communication; Errol Claire, ODFW, February 14, 1994). A recent report by the Oregon Water Resource Department (1986) estimated historic chinook salmon abundance in the John Day

Basin at 6,000 fish annually. However, the report did not specify the time period. Van Cleve and Ting (1960) also report interviews with local residents that suggested the John Day River supported larger runs in the 1930s than in the 1950s.

Habitat. Habitat loss in the John Day River prior to 1940 was extensive and resulted from mining, irrigation, grazing and timber harvest as in other basins in the region. Early agricultural practices were destructive of stream riparian habitats. Oliver (1967 p. 7-9) described land clearing on his father's ranch in the John Day Basin in the 1880s:

> ***"One of the first jobs on the Clark homestead was to clear off the brush and trees. Big cottonwoods grew all along the river and the meadows were covered by wild thorn bushes, to be chopped out by hand.***
>
> ***Father took out the big bends, straightened the channel, rip rapped the banks and made each meadow safe. He dried up the wet places. For draining, he dug by hand ditches about two feet deep and 18 inches wide. "***

Based on a contemporary understanding of the importance of riparian areas in the John Day Basin, the practices described above probably reduced salmonid standing stocks in the affected reaches (Tait et al. *in press;* Li et al. *in press).*

Loss of riparian areas and wetlands reduces the stability of a stream and increases the incidence of flashy flows and downcutting of the stream channel. In a study of a severely downcut stream in the John Day Basin in Meyers Canyon, a tributary to Bridge Creek, researchers estimated that the incision took place around 1920 and attributed it to Euroamerican perturbation in the watershed (personal communication; Dr. Robert Beschta, Oregon State University, February 11, 1994).

Changes in the Middle Fork of the John Day River between 1881 and the present were evaluated based on the general land survey of 1881 and a 1912 map of the Whitman National Forest (Welcher 1993). Since 1881, the width of the Middle Fork has increased 26 feet, and the active channel which meandered across the valley floor has been constrained to the southern valley wall. The forest map of 1912 shows multiple channels as well as cross valley meandering. Age of trees currently in the riparian zone suggests that the last time the middle fork was allowed to migrate across the valley floor was between 1903 and 1923. This coincides with the construction of a railroad grade (Welcher 1993).

Natural low summer flows, in the John Day River, were reduced further by irrigation diversions (Van Cleve and Ting 1960). A direct effect of irrigation was the use of gravel dams to divert water from the river. The dams were rebuilt every year in May and some were impassible to migrating adults. A diversion dam built around 1910 near the town of Spray blocked the migration of coho salmon for several years. The dam was washed out in 1934, but not before it eliminated the fall migrating salmon (Neal et al. 1993).

Gold was discovered in the John Day Basin in 1862. The search for gold buried in the gravels of the John Day River degraded major portions of the river's salmon habitat some of which have not recovered to this day. Mining operations silted over spawning gravels and diverted water out of the channel; and gold dredges removed gravel from the riverbed. Gold dredges operated in the John Day Basin until the late 1940's (Leethem 1979).

Life History. No information on life histories of chinook salmon prior to 1940 was found.

Deschutes River

Abundance. Early explorers reported that salmon were abundant in the Metolius River. Based on the amount of spawning gravel, full seeding of the Metolius River would have required 21,000 chinook salmon (Davidson 1953 cited in Nehlsen 1993).

Crooked River is a tributary to the Upper Deschutes River, which was subjected to early habitat degradation (see discussion below). Spring chinook that migrated to the Crooked River were extirpated by the early 1900s (Nehlsen 1993).

Habitat. There is little information on the historic condition of habitat in the Deschutes Basin. As in other watersheds located in the Cascade rainshadow, large scale irrigation was initiated in the later decades of the 19th Century. The first water for irrigation was diverted in 1871. The demand for water grew rapidly and by 1914 filings for rights to Deschutes River water above the City of Bend exceeded stream flow by 40 times (Nehlsen 1993).

Grazing also destroyed salmon habitat, and some of the most severe degradation occurred before the turn of the century. The timing of habitat degradation in Camp Creek, a tributary to Crooked River, was documented through an analysis of diaries and notes contained in land surveys (Buckley 1992). Downcutting, loss of riparian cover and desertification of the Price Valley and Camp Creek occurred after 1885 but prior to 1903. The dramatic changes in stream habitat came as a result of an interaction between variable climate and intense grazing by livestock brought into the basin by Euroamericans (Buckley 1992).

Life History. No information on histories of chinook salmon prior to 1940 was found.

Template Synopsis

The following summarizes the salient features of the template:

- Spring/summer chinook salmon were in decline by the turn of the century. The fishery compensated for the declining abundance of spring and summer chinook salmon by increasing the harvest of fall chinook salmon. After 1920, there was a severe decline of all races of chinook salmon.

- The general decline in abundance of spring, summer, and fall chinook salmon after 1920 was triggered by deteriorating ocean productivity and a shift to hot/dry climate which reduced the quality of freshwater habitats. The effect of an extended hot/dry weather pattern on salmon production was aggravated by previous massive habitat degradation.

- Harvest contributed to the decline of spring/summer chinook salmon around 1900, and of all races after 1920. Habitat destruction in the subbasins was severe enough by the late 1800's to account for a significant portion of the decline.

- Irrigation withdrawals, grazing, mining and timber harvest contributed to habitat degradation in the high desert streams of the mid-Columbia Basin. Significant loss of spawning and rearing habitat occurred before 1930.

- The available observations of juvenile life histories, though sparse, support the hypothesis that juvenile chinook salmon migrated/reared through the summer in the mainstems of the Columbia River and in the mid-Columbia Subbasins. Migration peaked in the summer.

- Historic flow patterns in the mainstem Columbia were consistent with extended summer migration of juvenile chinook salmon.

- **Similar to spring chinook salmon in other rivers, the juvenile spring/summer chinook in the mid-Columbia Basins probably migrated to sea as subyearlings and yearlings (ocean and stream types) with subyearling migration the dominant life history pattern.**

PATIENT DESCRIPTION

Abundance

The abundance of chinook salmon in the Columbia Basin continued the decline that started in 1920 (Figure 13 A) and extended it through the 1940s, 1950s and 1960s with slight increases in the 1970s and late 1980s (Figure 22). Recent harvests have reached historic lows. The harvest of chinook salmon in the Columbia River since 1940 has never approached the levels achieved from 1890 to 1920. The construction of Bonneville Dam allowed biologists to count salmon migrating upstream and make separate estimates of the minimum run to the river (catch and escapement) for each race of chinook salmon (Figure 23).

Fall chinook have dominated the run except for the early 1950s when the fall and spring run were about equal (Figure 23). Given a predevelopment estimate of 4.7 to 9.2 million chinook salmon in the annual run to the Columbia River (see page 25), the current total run of spring, summer and fall chinook salmon (river catch plus escapement) into the Columbia River is 8 to 15 percent of the predevelopment abundance. However, estimates of the run into the Columbia River do not include interceptions outside the basin.

Similar to the template description of abundance, the data in Figures 22 and 23 mask a significant shift in resource quality. In the late 1950's, following the development of more nutritious feeds, disease treatments and rearing practices, the survival of artificially propagated salmon increased and the percentage of hatchery origin fish in salmon populations began to increase (Lichatowich and Nicholas *in press).* In recent years, hatchery fish have made up 80% of the salmon returning to the Columbia River (NPPC 1992).

Habitat

Mainstem dams created obvious habitat changes in the mainstem Columbia and Snake rivers. Some dams are located within the migratory path of the juvenile and adult salmon from the study streams and these include one or more of the following: Bonneville (1938),[2] The Dalles (1957), John Day (1967), McNary (1953), Ice Harbor (1961), and Lower Monumental (1967) (Figure 24). In addition, large storage reservoirs in the headwaters of the Columbia Basin do not directly affect salmon migration in the mid-Columbia, but those dams are used to

[2] Date the dam construction was completed in parentheses

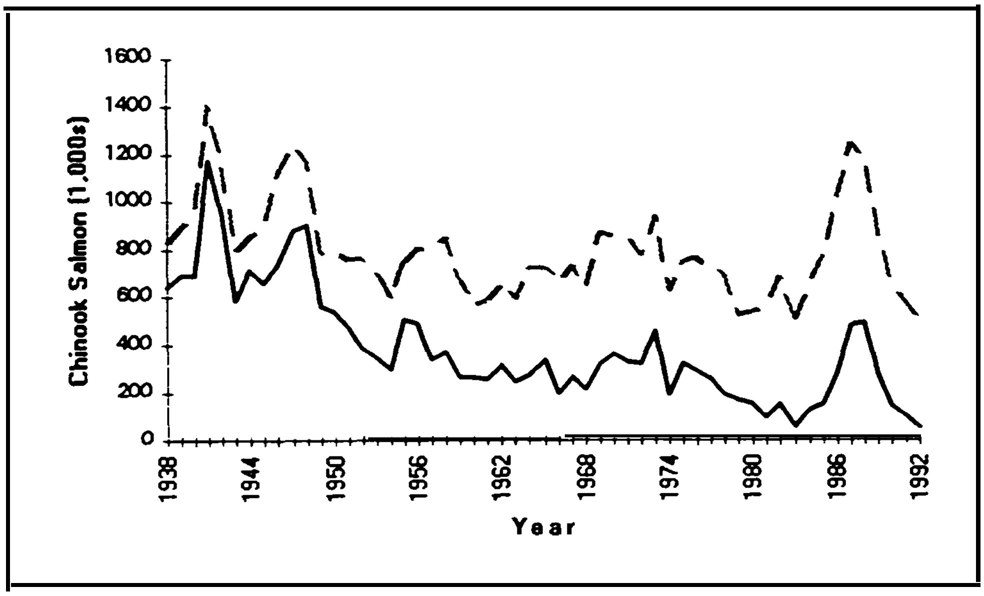


Figure 22. Commercial landings of chinook salmon in the Columbia River (solid line) (1938-1992). Dashed line is the estimated minimum run into the river. (Data from ODFW and WDF 1993).

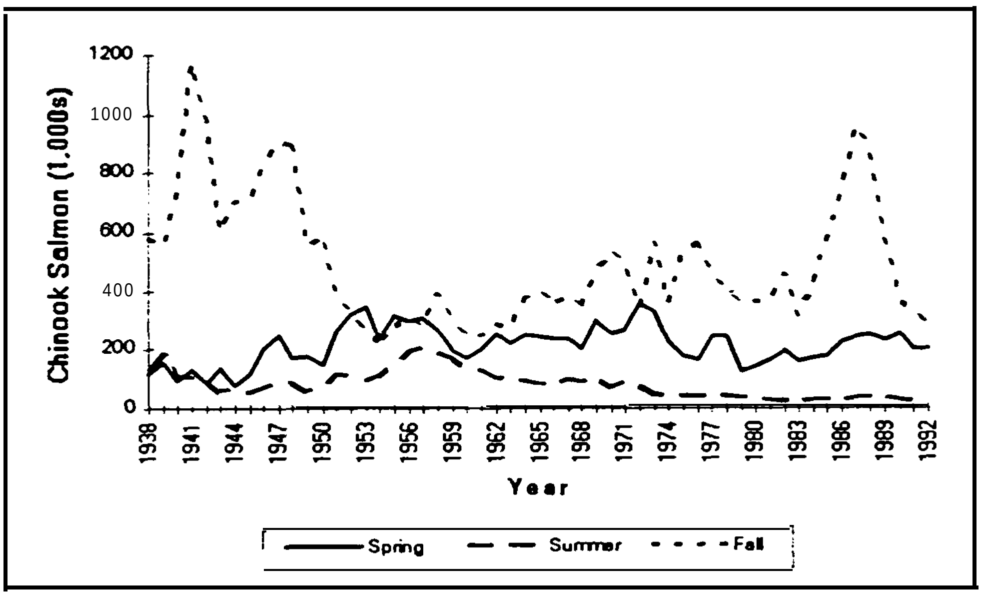


Figure 23. Minimum numbers of spring, summer and fall chinook salmon entering the Columbia River 1938-1992. (Data from ODFW and WDF 1993)

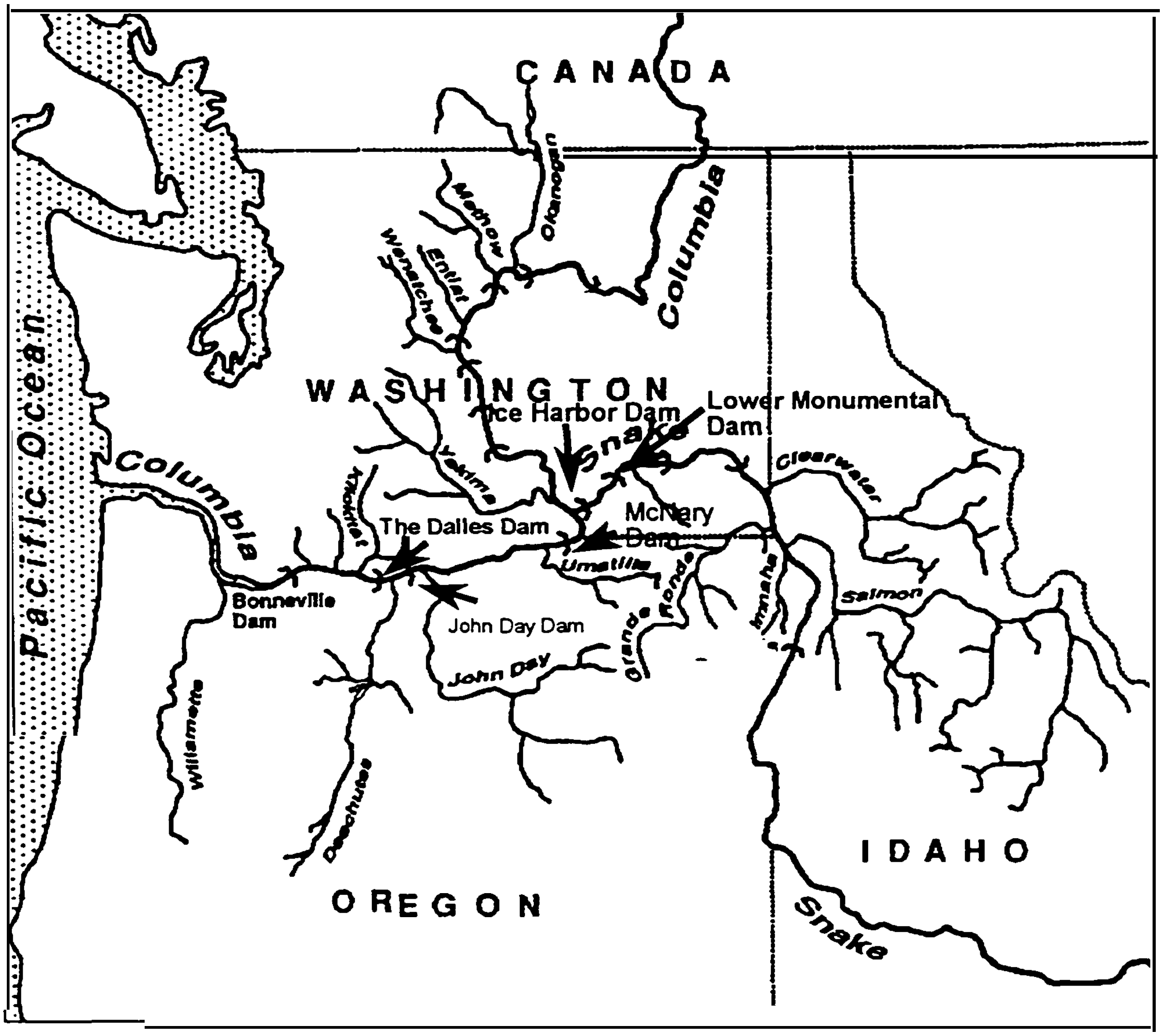


Figure 24. Map showing the location of mainstem dams within the migratory path of juvenile and adult salmon from streams covered in this study. (Taken from Fryer, et al. 1992)

manipulate seasonal flow patterns for power production. The result is a significant change in the natural flow patterns in the mainstem Columbia River (Figures 25 and 26).

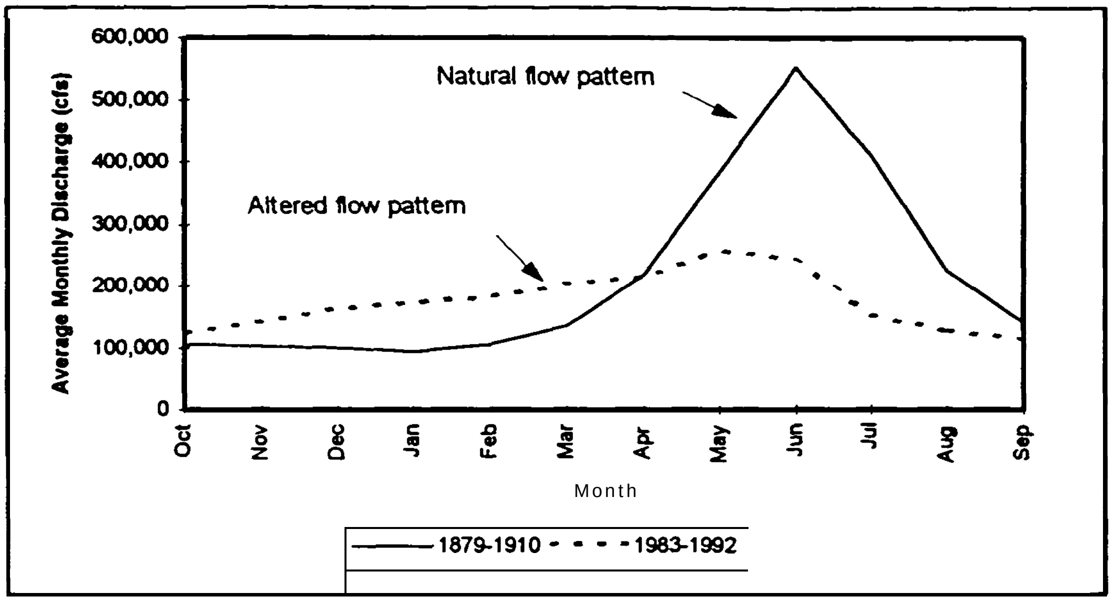


Figure 25. Change in monthly average flows for the periods 1879 to 1910 (natural) and 1983 to 1992 (altered) in the Columbia River at the Dalles, Oregon. (Data from Hydrosphere, Inc. 1990)

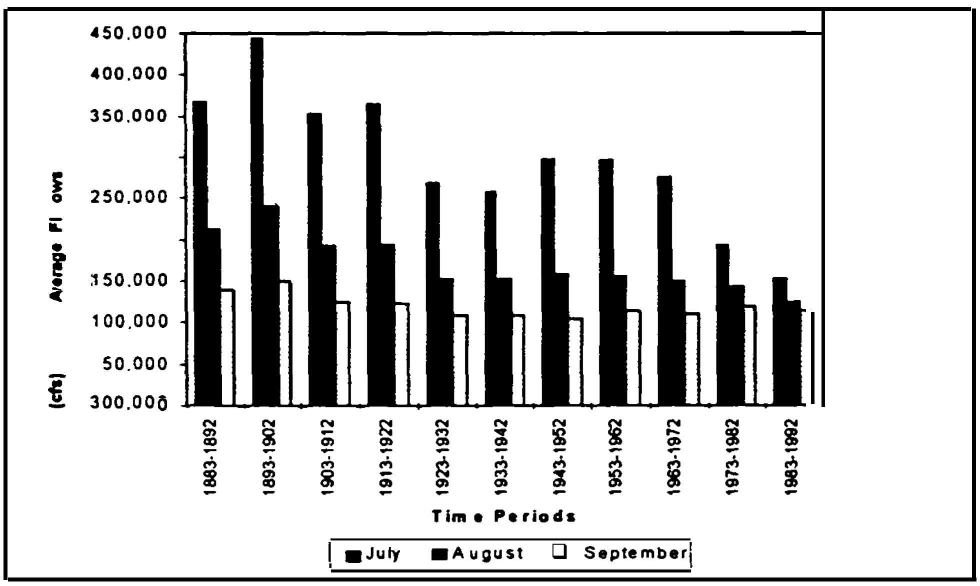


Figure 26. Average flows in the Columbia River at The Dalles for July, August and September for ten year intervals from 1883 to 1992. (Data from Hydrosphere, Inc. 1990)

The construction of storage reservoirs in the basin's headwaters altered the migration habitat of salmon in the mainstem Columbia River. Altered flows and river temperatures could interfere with life histories cued to the normal flow and temperature patterns. A mismatch between life history and an environmental factor such as flow can reduce survival. For example, coho salmon fry from a hatchery stock that exhibited an early time of spawning were planted into several streams in Oregon's coastal basins. Returning adults from the fry plants spawned but survival of their progeny was low. The early spawning adults deposited eggs in the gravel before the normal timing of winter freshets. Eggs subjected to the high flows failed to survive (Nickelson et al. 1986). In Carnation Creek, British Columbia, an increase in temperature following logging advanced smolt migration of coho salmon by less than 2 weeks. Although, the total number of smolts produced increased following logging, the change in smolt migration was followed by a decrease in smolt to adult survival (Holtby 1988).

The effect of altered flow patterns may extend into the estuary and the nearshore oceanic environments. The impoundment of summer flows and their release during the winter (Figure 25) has altered coastal sea surface salinities from California to Alaska (Ebbesmeyer and Tangborn 1993). The change in salinities could be an indication of other changes in coastal ecosystems due to altered flow patterns in the Columbia Basin (Ebbesmeyer and Tangborn 1993).

The mainstem dams and their operation are direct impediments to migration and sources of juvenile and adult mortality. The reservoirs behind the dams have altered the rearing habitat of juvenile salmon and the migratory habitat of juveniles and adults. Ecological changes in the river due to the dams and reservoirs and the introduction of exotic species have increased predation on/or competition with juvenile salmon. Mainstem dams and reservoirs slowed the migration of juvenile chinook salmon (Park 1969; Raymond 1969) which led to a hypothesis that survival is related to the rate of migration and that migration rate is determined by flow (NPPC 1994).

Many of the most egregious land and water development practices that degraded salmon habitat in the subbasins were gradually stopped or improved after 1940. Grazing pressure declined after the climate shifted in the early decades of this century. Gold mining declined and forest management came under better regulations designed to protect stream corridors especially after the 1970s. Irrigation diversions are slowly being screened. Some streams east of the Cascade Mountains have showed continued deterioration in habitat quality while others have improved over the past 50 years (e.g., McIntosh et al. 1994; Smith 1993). However, the development of the region from 1850 to 1940, particularly the appropriation and distribution of water for agriculture left behind a legacy of degraded habitat that time and increasing concern for salmon have not overcome.

Improvements in habitat quality have been observed in some streams since the 1930s (e.g., McIntosh et al. 1994; Smith 1993). However, it is important to remember that current conditions are compared to baseline measurements made in the 1930s. The baselines were established following 50 to 60 years of degradation. Even though some streams have shown improvements in salmon habitats, the quality of the habitat is still less than desired (Smith 1993).

Human economies and ecosystems coevolve (Norgaard 1994) and those coevolutionary processes in the Columbia Basin have established a developmental trajectory for the Columbia ecosystem characterized by diminished capacity for salmon production. The current crisis is the product of the interaction between the existing diminished habitat capacity and a natural low in the productivity cycle. Given the course of development in the Columbia River, each natural trough in productivity in the future will create an extinction crisis for some salmon stocks above Bonneville Dam.

LIFE HISTORY

Migration of juvenile chinook salmon in the Columbia River at Byers Landing near the confluence with the Snake River was monitored in 1954 and 1955 (Mains and Smith 1964). The study concluded that the migration of subyearling chinook salmon peaked in March and April. Yearling juveniles migrated later and peaked in June and July. Ages of the migrants were determined by examination of length frequency plots of the seasonal catch.

The use of length frequency to estimate age of juvenile chinook salmon may have introduced error into the analysis. For example, at Priest Rapids Dam the downstream migration of subyearling chinook salmon peaked between July 26 and August 13, and the migration of yearling chinook salmon peaked between May 7 and 23 (Becker 1985). Priest Rapids Dam is upstream from Byers Landing. The sequence of migration peaks for yearling and subyearling chinook salmon at Priest Rapids Dam are the reverse of those reported for Byers Landing (Mains and Smith 1964). The size of the juvenile salmon migrating in March and April (38 mm) (Mains and Smith 1964) was consistent with the expected size of subyearling fish. However, the summer migrants might have been both yearling and subyearling juvenile chinook. In fact, after June, the juvenile chinook salmon identified as yearlings by Mains and Smith (1964) were probably subyearlings. Scales taken from migrating juvenile chinook salmon in 1965 were used to verify the age of fish migrating past Priest Rapids Dam. Nearly all the juvenile chinook salmon collected in July and August were subyearlings (Park 1969).

The migration of juvenile chinook salmon through the mid-Columbia and lower Snake rivers is monitored at mainstem dams (e.g., DeHart 1992). A migration index of yearling and subyearling chinook salmon past McNary and Bonneville dams are shown in Figures 27 and 28 for 1988 through 1992. The yearling migration at Bonneville Dam was 90% complete by May 25, and the subyearling migration was 90% complete by July 8 in 1990.

The migration of juvenile chinook salmon was monitored by beach and purse seine about 100 miles below Bonneville Dam at RM 46. Both yearling and subyearling catch/effort by purse seine peaked in May. Beach seine catch/effort for yearling chinook salmon peaked in April, and for subyearling chinook salmon the catch/effort peaked in July (Figure 29) (Dawley et al. 1981).

Yearling and subyearling chinook salmon apparently had different vulnerabilities to the two collection methods. The purse seine captures larger juvenile salmon than the beach seine (Johnson and Sims 1973).

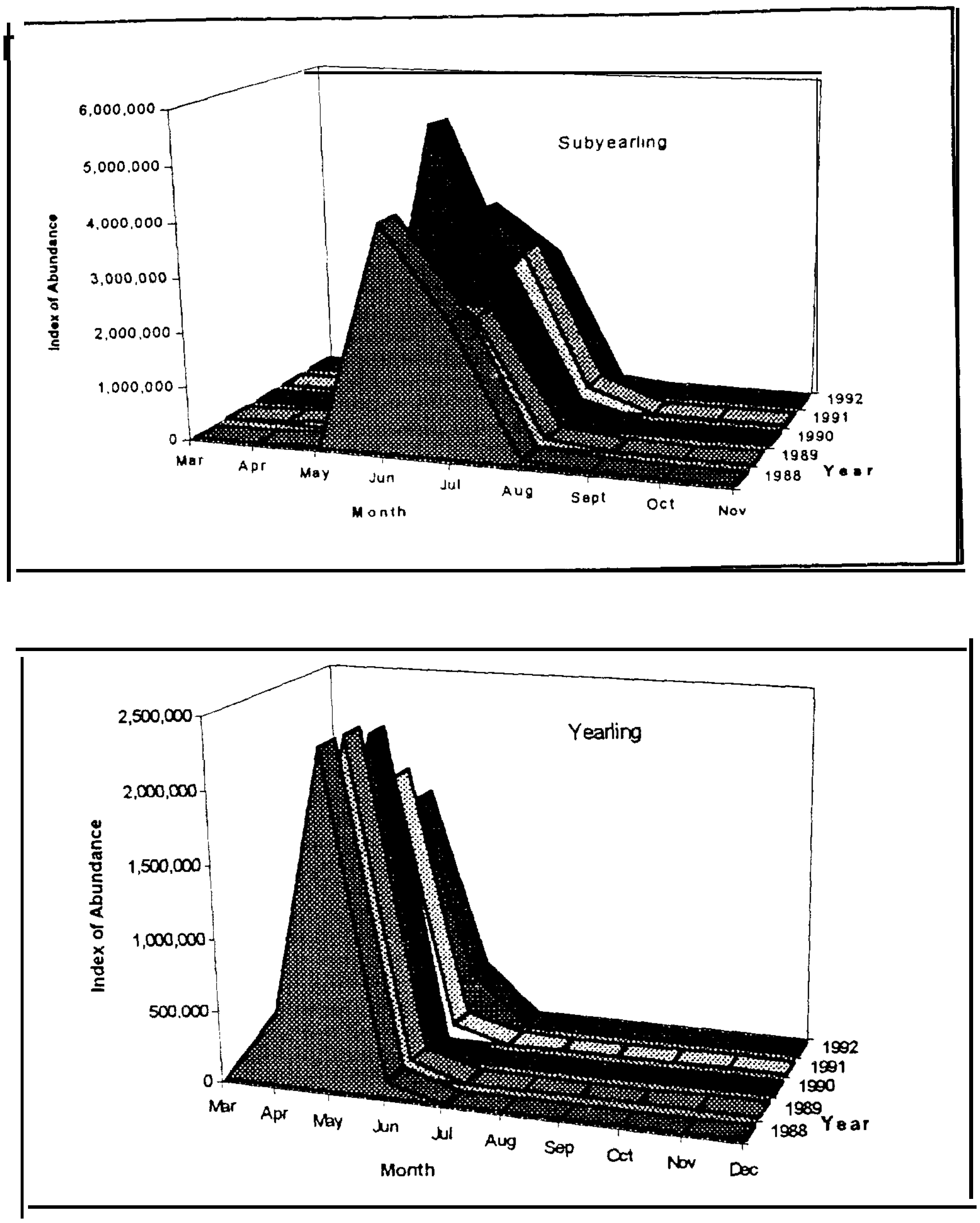
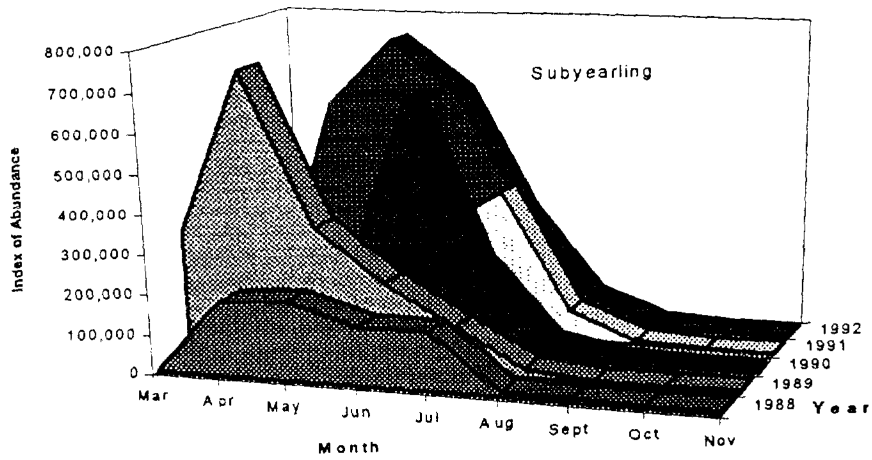


Figure 27. **The index of abundance of subyearling and yearling chinook salmon migrating past McNary Dam. (Data from** Fish Passage Center, Portland Oregon)



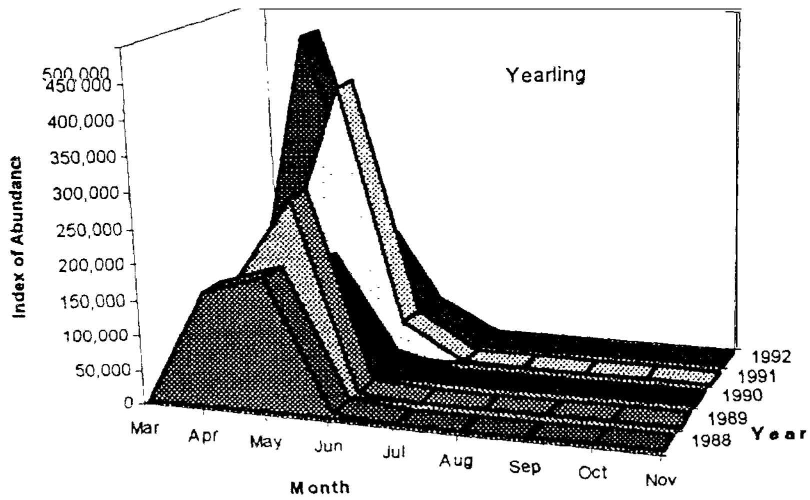


Figure 28. The index of abundance of subyearling and yearling chinook salmon migrating past Bonneville Dam. (Data from Fish **Passage** Center, Portland, Oregon)

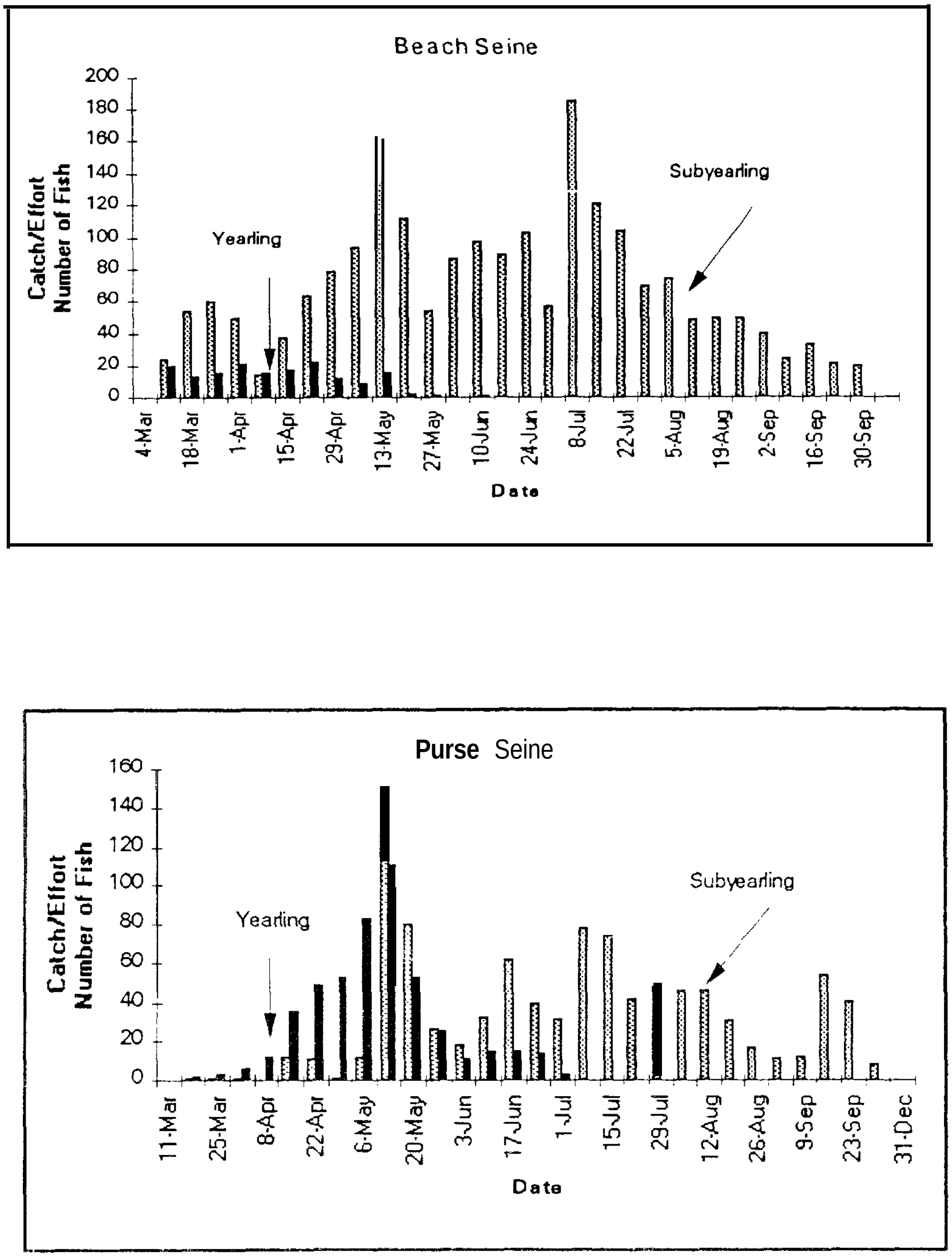


Figure 29. **Yearling and subyearling chinook salmon catch/effort of purse or beach seine at RM 46 in the Columbia River 1980. (From** Dawley et al. **1981)**

The age at maturity and juvenile life histories of spring chinook salmon was determined from scales sampled from fish collected at Bonneville Dam in 1987 through 1991 (Figure 30). Age four adults dominated the returning population. Nearly all the spring chinook salmon migrated to sea as yearlings (stream type) (Fryer et al. 1992).

Mid-Columbia Subbasins

Yakima River

Abundance. Since 1957, the return of adult spring chinook to the Yakima River has ranged from a low of 854 fish in 1972 to 12,665 in 1957 (Figure 31). Summer chinook from the Yakima River are extinct (CBFWA 1991). Recent escapements of fall chinook to the Yakima River are estimated at 2,400 natural and hatchery produced fish (CBFWA 1991).

Habitat. Smith (1993) compared stream reaches that were surveyed in 1935-1936 in the Little Naches River and Taneum Creek with identical stream reaches resurveyed in 1990. Pool habitat increased between 1935 and 1990 but is still deficient when compared to west side streams. Spawning habit and substrate quality decreased between the two surveys (Smith 1993).

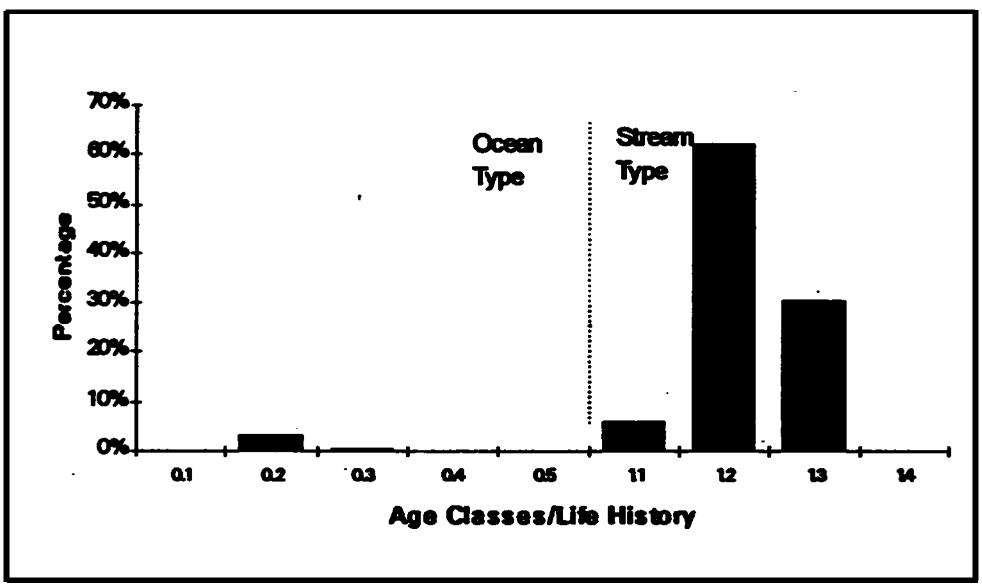


Figure 30. Juvenile life histories and average age of adult spring chinook salmon sampled at Bonneville Dam 1987 to 1990. (Data from Fryer et al. 1992)

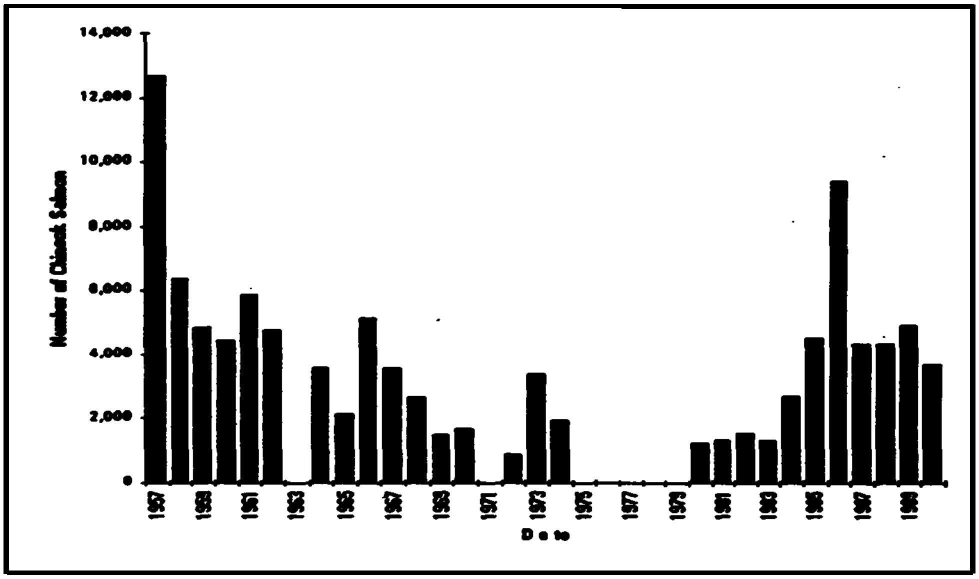


Figure 31. Estimated run of spring chinook salmon to the Yakima River 1951 to 1990. Total run not estimated in 1963,1971,1975 to 1979. (Data from Fast et al. 1991)

Smith (1993) concluded that the structure of salmonid habitat had been significantly degraded prior to 1935 due to cumulative impacts of past grazing, recreational use of the river and timber harvest. Salmon habitat. in the surveyed . reaches showed evidence of a cycle of decline and recovery. Prior to 1935, grazing and pasture burning which caused extensive forest fires degraded salmon habitat. After 1935, salmon habitat showed signs of recovery until the 196Os, followed by a new cycle of decline as timber harvest intensified. The post 1935 cycle of recovery and degradation was determined from an analysis of aerial photographs (Smith 1993).

In addition to the structural features of salmon' habitat analyzed by Smith (1993), water use in the basin is also a major constraint on salmon production in the Yakima Basin. Diversion dams with inadequate bypasses for parr and smolts and as many as 67 small to medium diversions still have inadequate, obsolete or deteriorating screening. Water diversions have created excessive temperatures in the lower reaches of the Yakima River.. Temperatures below Sunnyside Dam (Figure 19) frequently exceed 75°F and sometimes reach 80°F -in July and August. In addition to reduced flows and excessive temperatures in the lower river, low flows in the winter and higher than normal flows in the summer in the canyon area are also detrimental to chinook salmon production (CTYIN et al. 19901.

In a study of the effect of different water management scenarios on the stream temperatures in the Yakima River, the water management scenario that was most effective at reducing temperature used 1981 reservoir releases with no diversions and no return flows, i.e., 1981 reservoir operation but no irrigation diversions (Vaccaro 1986). However, even with that scenario, there was little improvement in the summer water temperatures in the lower river. A return to natural stream flows was least effective in reducing temperature-(Vaccaro 1986). However, all the scenarios were evaluated under the current stream channel configuration and riparian cover. Natural flow patterns in a predevelopment stream channel bordered by healthy riparian vegetation would have resulted in lower stream temperatures.

Life History. The principal spawning areas for spring chinook are the Yakima River above Ellensburg and the upper Naches and American rivers. Adults enter the river and begin passing Prosser Dam RM 47.1 in April. The earliest arrival date is April 11 and median passage at Prosser is between May 12 and May 28 (Fast et al. 1991).

Emergence begins in March and continues through mid-June. Juvenile rearing areas fluctuate seasonally and extend further downstream than the spawning distribution. The extent of the downstream rearing distribution varies from year to year depending on temperature. Juvenile spring chinook undertake at least two in basin migrations prior to the smolt outmigration. Fry redistribute themselves downstream from the spawning areas in the upper Yakima River soon -after emergence. This migration may extend downstream as far as Prosser, however, most fry remain above the confluence with the Naches River. Few juveniles are found below the Naches during the summer. Juvenile chinook salmon reach their highest concentration in the canyon (RM 129-146) (CTYIN et al. 1990). Fry emerging in the American River redistribute to the middle Naches River to rear, and fry emerging in the upper Naches move to the lower river or into the Yakima River near its confluence with the Naches. Some juvenile spring chinook begin a second migration in late October as temperatures decline. Those juveniles move below Prosser to overwinter (CNIN et al. 1990).

. The outmigration of smolts takes place from March through -late June. Until recently it was believed that all Yakima River spring chinook migrated to sea as yearlings. However, recent electrophoric analysis of juvenile chinook salmon migrating in July showed that 40% of the fish over 90 mm were spring chinook (Busack et al. 1991). Those fish may have been yearlings migrating very late or larger subyearlings. Unfortunately no scales were taken to verify age. Juvenile spring chinook have shown a propensity to migrate as subyearlings in the summer in years when flows and temperatures are favorable (personal communication; Bruce Watson, YIN).

Fall chinook salmon spawn in the lower mainstem of the Yakima River. Fisheries managers estimate that 30% of the fall chinook spawn above Prosser. Fall chinook also spawn in Marian Drain which is an irrigation return for the Wapato

Project. The fall chinook spawning migration begins in mid-October and is complete by the third week in November (CTYIN et al. 1990).

Emergence of fall chinook fry peaks in late February. They begin moving past Prosser Dam by late April or early May. Since 1983, the migration of fall chinook smolts at Prosser Dam has been 95% complete between June 17 and July 8 (CTYIN et al. 1990). In 1989, WDF operated a scoop trap below Prosser Dam at RM 7. The catch of juvenile chinook salmon peaked on June 9. Instream mortality of marked release groups of hatchery produced fall chinook was high, ranging from 49% to 90%. Similar trapping in 1992 revealed that low flows periodically caused lethal conditions (high temperatures) for juvenile chinook salmon in the lower Yakima River and heavy predation by small mouth bass, catfish and gulls. In 1992, the outmigration of juvenile chinook salmon was complete by June 20 (personal communication in the form of draft manuscripts; Bruce Watson, YIN).

Patient life history patterns of spring chinook described by Watson (personal communication; Bruce Watson, YIN, 1992) show two life histories which were -present in the template period that are now absent (Table 3). The ocean type life history pattern is no longer present.. Spring chinook with a stream type life history, specifically those that utilized the lower river tributaries are also no longer present.

Table 3. Description of patient life history patterns in Yakima River spring chinook salmon. (personal communication; Bruce Watson, YIN, 1992)

No.	Spawning Location	Summer Rearing Location (fry to parr)	Winter Rearing Location (pre-smolts)	Smolt Migration Route (subbasin)	Smolt Age
I	Upper tributaries	Upper tributaries	Upper tributaries	Entire drainage	I+
II	Upper tributaries	Upper mainstem	Upper mainstem	~90% of drainage	I+
III	Upper mainstem	Upper mainstem	Upper mainstem	~90% of drainage	I+
V	All drainage units above lower mainstem	All drainage units above lower mainstem	Lower mainstem & associated "sloughs"	<50% of drainage	I+

Tucannon River

Abundance. Escapement of spring chinook salmon to the Tucannon River has averaged 210 fish since 1971. Fall chinook spawning is limited to the lower river below Sarbuck Dam. Between 1976 and 1980, the number of fall chinook salmon redds ranged from 20 to 200. After 1985, standardized'surveys were initiated. No redds were observed in 1985 and 1986. In 1987, 1988, 1989 redd counts were 16, 26 and 59, respectively (WDF et al. 1990).

Habitat. The Tucannon River can be divided into four zones based on habitat quality: the mouth to Pataha Creek (RM 10); Pataha Creek to Marengo (RM 24), Marengo to headwaters; and Pataha Creek (WDF et al. 1990) (Figure 32). Habitat deteriorates in a downstream gradient. The lowest reach up to Pataha Creek contains the poorest physical habitat for salmon due to elevated temperatures, heavy sedimentation, irrigation diversion, and degraded riparian zone. The area from Pataha Creek to Marengo also experiences summer stream temperatures at or above the lethal limits for salmonids and experiences the other problems identified in the lowest reach. Habitat conditions improve near Cummings Creek (RM 35) and continue to improve upstream from that point. Salmon production in Pataha Creek is primarily limited by high sedimentation, high road density and chemical pollution associated with agriculture (WDF et al. 19901.

ife History. Spring chinook begin spawning- in late August. Spawning peaks in the first or second week in September and is completed by the end of September. Spring chinook fry generally emerge in February. Migration of juvenile chinook. salmon was monitored in the mid-l 950s with Fyke nets at the mouth of the river and at RM 18 (Mains and Smith 1955 cited in WDF et al. 1990). The pattern of juvenile migration showed peaks in November, April and May. The majority of the juveniles were trapped in April and May. In recent years, a migration of yearlings peaked between April 26 and May 10. The mean length of the migrants was 89 mm (WDF et al. 1990).

Umatilla River

Abundance. A program to reintroduce spring and fall chinook and coho salmon and enhance steelhead in the Umatilla River was recently initiated. Prior to the restoration program, steelhead escapement to the river averaged 2,091 adults (1966-l 987). Hatchery releases have produced recent spring chinook returns ranging from 13 to 1,291 fish between 1988 and 1991. Fall chinook returns from hatchery plants ranged from 61 to 468 adult fish between 1985-1991 (Lichatowich 1992).

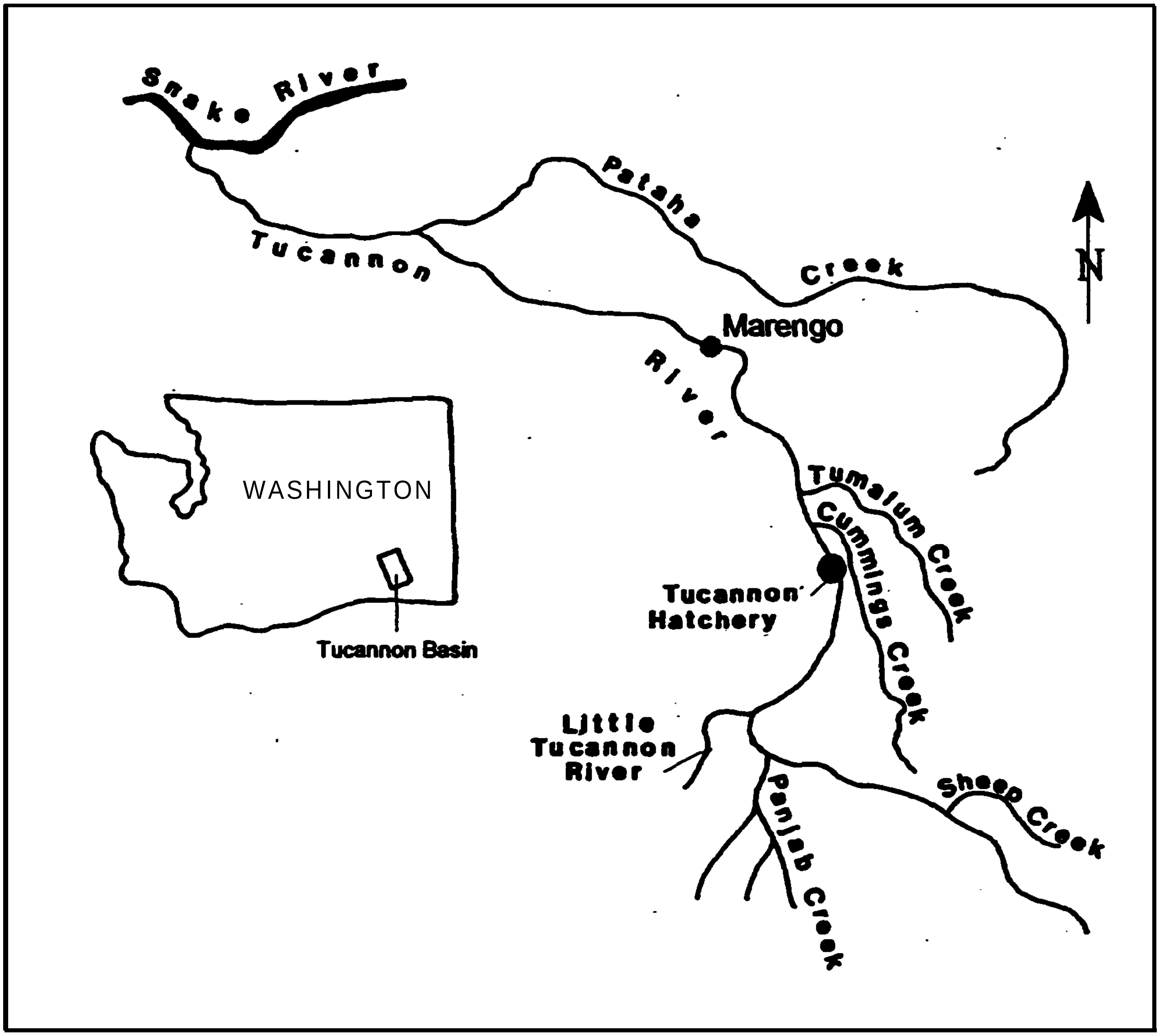


Figure 32. Tucannon River showing locations mentioned in the text. (From Bugert et al. 1991)

Habitat. The Umatilla River restoration program includes major investments in water management to provide partial restoration of lower river flows for fish passage. Irrigation is the principal water use that conflicts with salmon production and habitat quality. The basin has nearly 4,000 water rights on record for a total of 4,600 cubic feet per second. This level of water withdrawal has rendered the lower 32 miles of the Umatilla River unsuitable for summer and early fall rearing of salmonids. In low flow years, problems may develop early enough to impede the spring outmigration of juveniles and upstream migration of spring chinook adults (CTUIR and ODFW 1990).

Riparian zones are generally healthy in the higher elevations, however livestock grazing, road building and timber harvest have degraded mid-elevation riparian zones, and in the lower elevations riparian zones are in poor condition (CTUIR and ODFW 1990).

Life History. Studies of the life history of reintroduced chinook salmon in the Umatilla Basin have recently been initiated.

John Day River

Abundance. Escapement of spring chinook salmon into the John Day River ranged from 918 to 1,923 fish between 1978 and 1985 (Lindsay et al. 1986). Fall chinook escapement into the John Day River is estimated at 100 fish (Olsen et al. 1992).

Habitat. The summer rearing distribution of spring chinook in the north and middle forks of the John Day River appears to be limited by temperature (Figure 33). Juvenile chinook salmon were not found below thermograph stations that had reached a temperature of 20°C (68°F) (Lindsay et al. 1986). After emergence, juvenile spring chinook moved downstream, usually from May through. July. As flows decreased and temperatures increased the juveniles moved back upstream (Figure 33). The largest constriction of habitat occurs in August, although, in some years the constriction could occur as early as July. By October, when temperatures cooled, the juveniles moved downstream again (Lindsay et al. 1986). The John Day River supports extensive irrigation (Oregon Water Resources Department 1986) which contributes to low summer flows and temperature problems.

The resurgence of gold mining following an increase in the government controlled price of gold (Leethem 1979) devastated salmon habitat in the 1930s and 1940s (Neal et al. 1993). The introduction of exotic predators (small mouth bass and - channel catfish) have also altered the biological habitat for juvenile chinook salmon. Grazing in the riparian zones of the John Day River have contributed to elevated temperatures, bank erosion, siltation and intermittent flows (Li et al. *in*

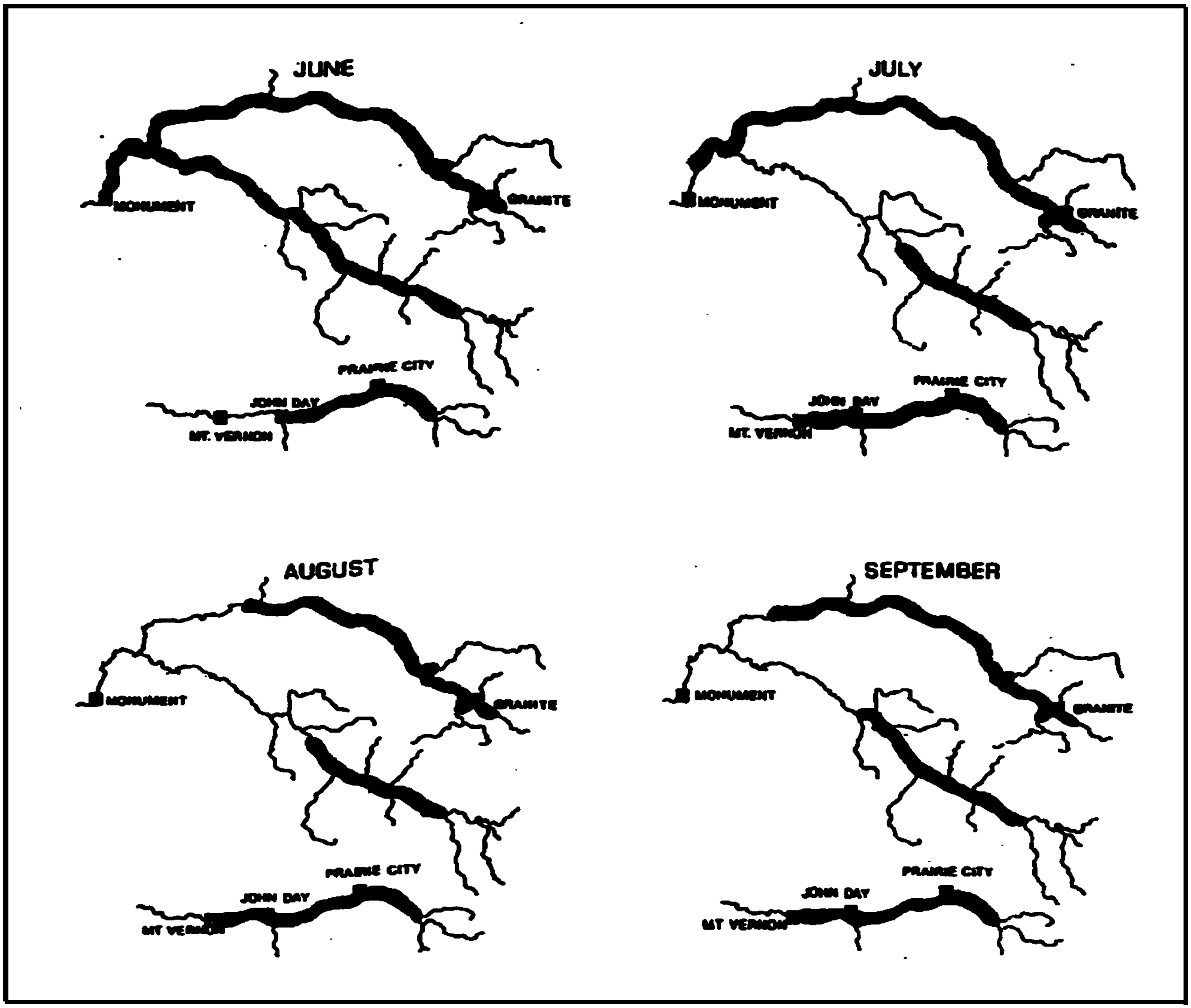


Figure 33. Shifting rearing distributions of O-Age spring chinook salmon June-September 1981 in the John Day Basin. (Lindsay et al. 1981)

press). The loss of riparian cover has a greater negative impact on salmonids in desert streams such as those in this study, than in streams west of the Cascade Mountain Range (Li et al. *in press).*

_ife History. Spring chinook spawning in the John Day River takes place from late August through September. Examination of coded wire tags recovered on spawning grounds show a high degree of adult homing fidelity. Adult fish returned to spawn in the same areas where they were captured and tagged as juveniles (Lindsay et al. 1986).

Juvenile spring chinook salmon emerged from the gravel in February and March in the mainstem John Day River and in April in the North Fork. Smolt migration out of the upper rearing areas of the North and Middle forks and the mainstem took place from February-through May. Smolt migration lower in the river at Spray took place from mid-February to mid-June with a peak during the first two weeks in April. Nearly all juveniles migrate to sea as yearlings (Lindsay et al. 1986). The summer movement of juvenile spring chinook salmon in the John Day River (Figure 33), suggests that cooler river temperatures through the lower mainstem could produce an ocean type life history.

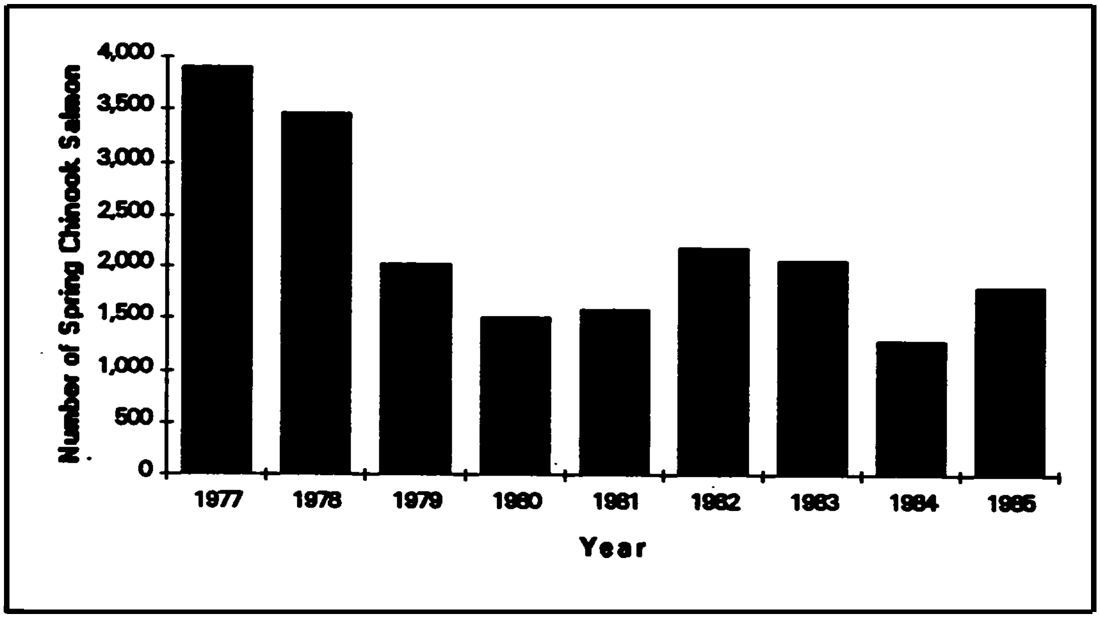
Deschutes River

Abundance. In river catch and escapement of spring chinook in the Deschutes River (1977-l 985) ranged form 3,895 to 1,290 fish. Catch and-escapement of wild fall chinook (1977-1988) ranged from 5,219 to 11,772 fish (Figure 34) (ODFW and CTWSR 1990).

Habitat. Unlike the other subbasins discussed thus far, the lower Deschutes River is not plagued with excessive temperatures. However, the only remaining spawning areas for spring chinook salmon is in the two tributaries, the Warm Springs River and Shittike Creek. Those streams do experience elevated temperature in their lower reaches in summer (ODFW and CTWSR 1990).

The Pelton-Round Butte Hydroelectric complex eliminated anadromous salmon production in the upper Deschutes River, including tributaries such as the Metolius River. The anadromous runs have been blocked since 1958 at RM 100 by the Pelton Reregulating Dam.

For fall chinook, the major habitat constraints are the quantity and quality of spawning gravel. Sedimentation from glacial silt below the confluence with White River and sedimentation from grazing and recreation have degraded gravel quality while Round Butte and Pelton dams have influenced the quantity of gravel (ODFW and CTWSR 1990).



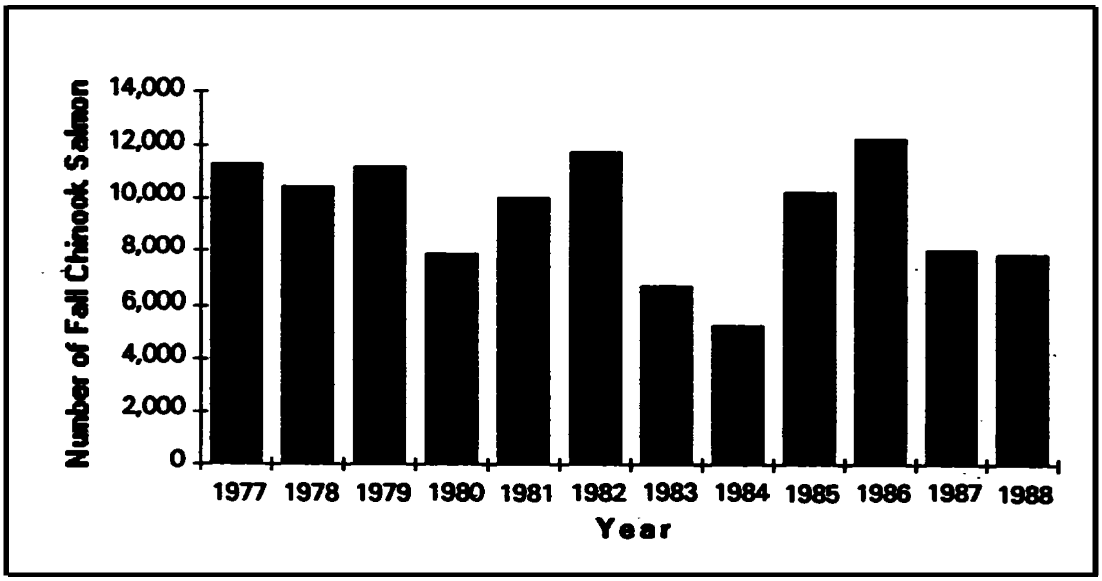


Figure 34. Total number of naturally produced spring and fall chinook adults returning to the Deschutes River (1977-1933). Annual estimates include harvest, escapement and for spring chinook, brood fish sent to Warm Springs and Round **Butte** Hatcheries. (From ODFW and CTWSR 1990).

Ceratomyxa Shasta is a biological factor constraining the production of chinook salmon in the Deschutes River. Juvenile chinook salmon in the mainstem Deschutes probably incur high mortality in July due to the seasonally high infection rate of the parasite. The presence of C. *Shasta* and its impact on juvenile chinook salmon might be aggravated by spore production from rainbow trout in Lake Simtustus. Juvenile chinook salmon in the mainstem Deschutes River between May/June and September are subjected to high mortality (Ratliff 1981).

Life history. Most spring chinook spawn in the Warm Springs River; a few also spawn in Shittike Creek. The juveniles emerge in February and March and rear in all major spawning areas. Migration of juvenile spring chinook salmon in the Warm Springs River peaks in fall from September to December and in spring from February through May (Lindsay et al. 1989). Most of the juveniles that migrate from the Warm Springs River in the fall over-winter in the mainstem Deschutes or Columbia rivers then migrate to sea the following spring. About 1% of the juveniles migrate to sea as subyearlings (Lindsay et al. 1989).

Fall chinook spawn throughout the mainstem of the Deschutes River below the Pelton Reregulating Dam. The heaviest concentration of spawners is in the upper six miles of the accessible river. Spawning begins in late September, peaks in November and is completed by December. Scales were sampled from fall chinook returning to the Deschutes River and 96 percent had the ocean type life history (Jonasson and Lindsay 1988).

Juvenile fall chinook emerge from the gravel in February. Emergence was completed by April from the mouth of the Deschutes River to Dry Creek and May for the area from Dry Creek to the Pelton Reregulating Dam. Fall chinook reared in areas and densities that correspond to the density and area of spawning. Peak migration to sea is in the summer of their first year at lengths ranging from 80-92 mm. The larger juveniles migrate downstream first. Migration through the lower river takes place from May to early July (Jonasson and Lindsay 1988).

Patient Synopsis

- The abundance of chinook salmon continued to decline in the 1940s and 1950s followed by another major shift in resource quality as natural production declined and hatchery production increased in importance.

- Habitat continued to degrade in some streams while others showed evidence of improvement.

- **Salmon habitat in the Yakima, Tucannon, Umatilla and John Day rivers is fragmented. The lower reaches of those streams are barriers to juvenile migration during summer months due to lethal stream temperatures. The mainstem Deschutes is not subject to a thermal barrier but C. *shasta* may constitute a barrier preventing juvenile chinook salmon from effectively rearing or migrating through the mainstem during the summer months.**

- **Although there is evidence to suggest that juvenile spring chinook salmon did undertake summer migration (ocean' type life history), poor habitat conditions prevent the expression of that life history pattern in all the subbasins.**

- **Seasonal flow patterns in the mainstem Columbia have shifted dramatically. The current flow patterns probably do not favor extended migration of spring chinook salmon through the summer and.early fall months.**

- **Changes in seasonal flow patterns in the mainstem Columbia River may alter habitat quality in the estuary and nearshore ocean.**

- **Mainstem dams have increased mortality of juvenile and adult migrants.**

DIAGNOSIS

Quantity and Quality of the Resource

Intensification of commercial exploitation of chinook salmon in the Columbia River began in 1866. Since then, the harvest of chinook salmon can be divided into four phases: Initial development-of the fishery (1866-1888); a period of sustained harvest with an average annual catch of about 25 million pounds (1889-1922); resource decline with an average annual harvest of 15 million pounds (1323-l 958); **and maintenance at a depressed level of production of about 5 million pounds (1958 to the present) (Figure 35). Recent declines may indicate the system is slipping to a new, lower level of productivity. Using the same data as shown in Figure 35, Mundy (in *press*) identified five phases in the commercial harvest of chinook salmon in the Columbia River. Mundy's five phases started with the years 1866, 1884, 1921, 1932 and 1953. Our four phases and Mundy's five phases generally agree with the four phases shown in Figure 35, except Mundy divided our phase three (decline) into the years prior to and after construction of the mainstem dams.**

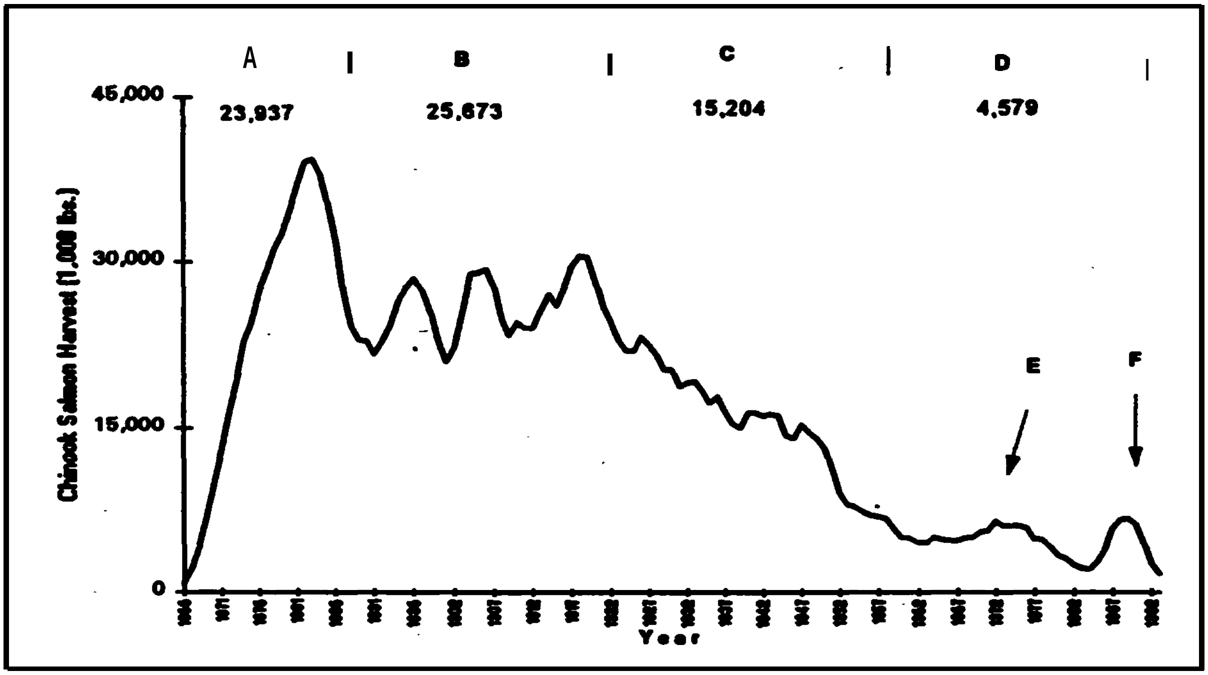


Figure 35. Five year running average of chinook salmon harvest in the Columbia River (1866 to 1332). Time periods A-D explained in the text. Numbers within each period are average harvest. E and F are recent peaks in harvest. **(From Reiningen 1976; ODFW and WDF** 1993)

The data presented in Figure 35 and the four stages derived from those data are based entirely on measures of resource quantity — the pounds of fish harvested. The pattern of resource quantity shown in Figure 35 masks an important shift in quality that took place between 1890 and 1920. The racial composition of the 'harvest and apparently the productivity of the individual races of chinook salmon were changing (Figures 14 and 15). Spring and summer chinook salmon declined significantly between 1883 and 1920; and to maintain production, harvest shifted to fall chinook salmon. The decline of the spring/summer races represents a loss of the biodiversity within the chinook salmon of the Columbia Basin. It was suggested, that the decline in spring/summer chinook probably started by 1911 (Craig and Hacker 19401. However, the timing of habitat degradation in the mid-Columbia subbasins suggests that the decline in productivity probably started before the turn of the century.

After the 196Os, increases in the survival of hatchery reared fish created another shift in resource quality. Natural production continued to decline and was numerically replaced with hatchery fish. Salmon of hatchery origin now make up about 80% of the total adult run into the Columbia River (NPPC 1992). Artificial propagation of salmon in the Columbia Basin has not been-able to return production to the pm-1920 levels or induce a sustained increasing trend (see Figure 35).

Hatchery programs have traditionally been focused on production numbers (quantity rather than quality).[3] Restoration and management also focus on quantity and ignore resource quality. Between 1890 and the present, there has been a continuing loss of biodiversity, loss of natural productivii and loss of quality in the chinook salmon resource. The strictly numerical approach has not proven effective in the past in the Columbia River or in other regional redevelopment programs (Regier and Baskerville 1986). Restoration objectives should contain targets for resource quality as well as quantity (RASP 1992).

Chinook Salmon Declines in the Subbasins

The Yakima is the only river among those included in this study, for which predevelopment estimates of the abundance of chinook salmon are availabte (Table 4). In the period roughly corresponding to the early development and sustainable harvest (Phases A and B) in Figure 85, salmon in the Yakima River declined from an estimated annual run of about 500,000 to 20,000 adults, Some of the decline

[3] In-hatchery quality of the juvenile salmon has received attention. Quality as used here refers to ecological quality of hatchery reared fish based on their performance once they are released into the ecosystem.

Table 4. Abundance of chinook salmon in mid-Columbia tributaries In the template (1860-1940) and patient (1941-present) periods. (See **text for data sources)**

Tributary	**Template Abundance**	**Patient Abundance**
Yakima	Prior to 1847 500,000 predominately **chinook** **1847-1905** 1 OO,OOO-20,000 chinook salmon **1905-1930** '20,000 chinook **salmon** **1930-1949** -1,000-l ,500 spring **chinook**	854-l 2,665 spring **chinook.** Summer chinook, **extinct.** 2,400 fall chinook.
Tucannon	**No estimate**	**2,400 average and up** to 5,000 spring chinook in the 1950s. **Recent average 200 spring chinook.** **0-59 fall chinook redds.**
Umatilla	Large numbers of salmon in river in 1914 from anecdotal evidence.	**Native chinook extirpated.** Restoration program recently initiated. Natural production not **known.**
John Day	Large numbers of salmon from anecdotal evidence.	918-l ,323 spring **chinook escapement.** **~100 fall chinook**
Deschutes	Large numbers of salmon from anecdotal evidence.	1,290-3,895 spring **chinook,** **5,219-11,772 fall chinook.**

represents interception fisheries in the lower Columbia. However, the template discussion suggests early and significant destruction of habitat in the mid-Columbia Subbasins. An important part of the early decline in chinook salmon was certainly a consequence of habitat destruction.

The decline of chinook salmon in the Yakima River is probably consistent with the magnitude and timing of declines in the other streams in this study. In the Umatilla River, large numbers of fish were reported in the river as late as 1914 but the construction of two dams in the lower river extirpated chinook salmon before the 1920s. Anecdotal information suggests much larger runs of chinook salmon in the Deschutes and John Day rivers than today.

Habitat Degradation

The decline of spring/summer chinook early in this century was attributed to overharvest and habitat destruction (Craig and Hacker 1940) with overharvest generally receiving the greater emphasis (Mundy *in press*). However, spring and summer chinook were particularly vulnerable to the kinds of habitat degradation that took place in the last decades of the 19th and early decades of the 20th centuries. Grazing and timber harvest stripped away riparian vegetation and wetlands were drained. In the high desert subbasins, the loss of riparian cover has significant effects on the quality of salmon habitat including structural complexity and temperature (Li et al. *in* press). Water temperatures in the high desert rivers are more sensitive to loss of riparian cover and are more likely to exhibit negative effects on salmonids than streams west of the Cascade Mountains (Li et al. *in press).*

Another important source of habitat degradation was gravity irrigation systems which diverted water from rivers at higher elevations for distribution to farms at lower-elevations. Irrigation diversions would have impacted production of spring and summer chinook salmon to a greater degree than fall chinook salmon. Spring and summer chinook generally spawn in the upper or middle reaches of a river above irrigation diversions whereas the spawning distributions of fall chinook salmon are largely below the diversions (Figures 36-39).

The spawning distribution of spring and summer chinook salmon and the location of irrigation diversions create a major conflict between unscreened diversions and juvenile spring/summer chinook salmon — more specifically, spring/summer chinook salmon with the ocean type life history pattern. Juvenile chinook salmon with the ocean type life history migrate downstream in late spring and summer at the same time that there is high demand for irrigation water. Those fish would have been diverted into irrigation ditches and left to die in large numbers in the

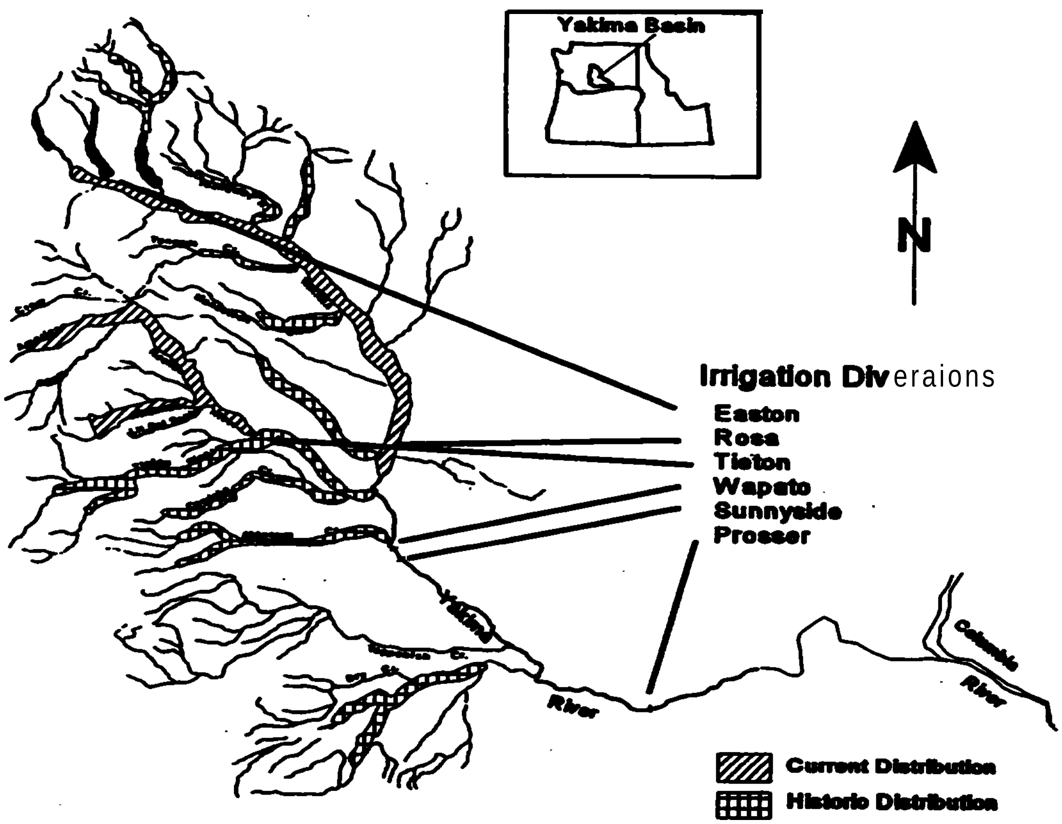


Figure 36. Location of major irrigation **diversions** and the current and hlstorlc spawning distrlbutlon of spring chinook salmon in the Yaklme **Basin. (Distributions are estimates obtained from CTYIN et al. • 1990; personal communication; Bruce Watson, YIN, August 31, 1994)**

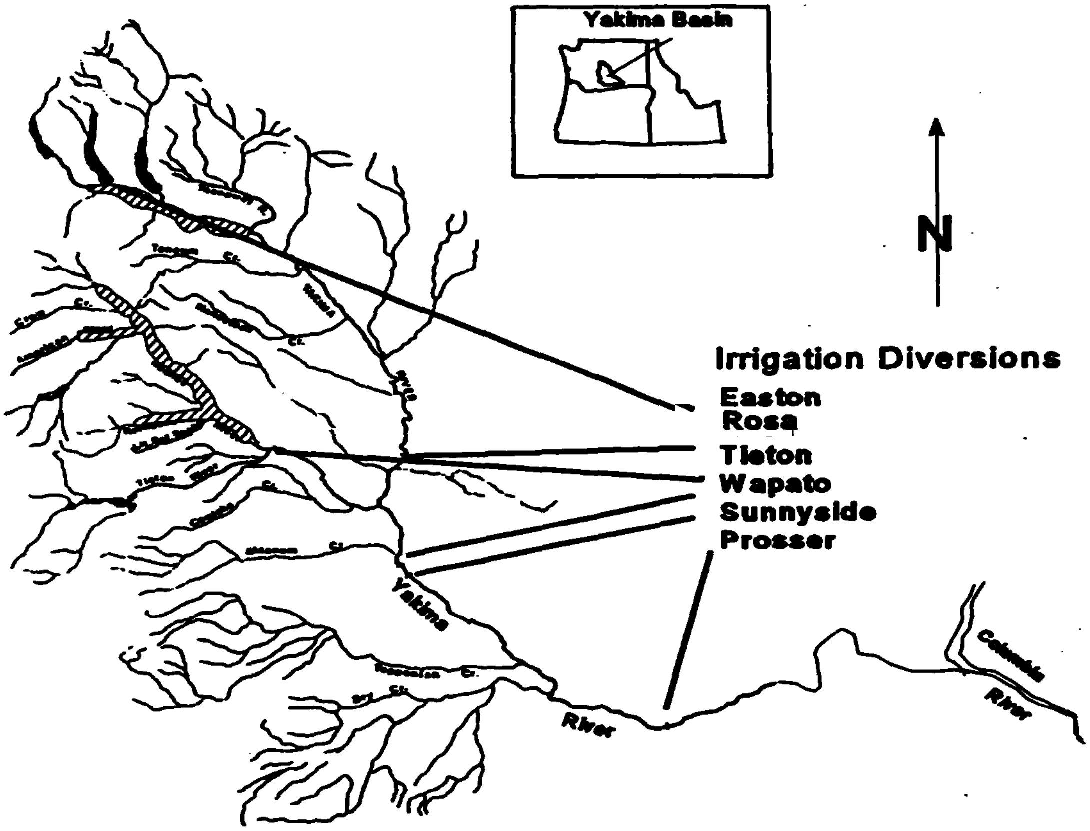


Figure 37. Areas in the Yakima Basin where 83 percent of the current spring chinook salmon spawning takes place. **(personal communication; Bruce Watson, YIN, August 31, 1994)**

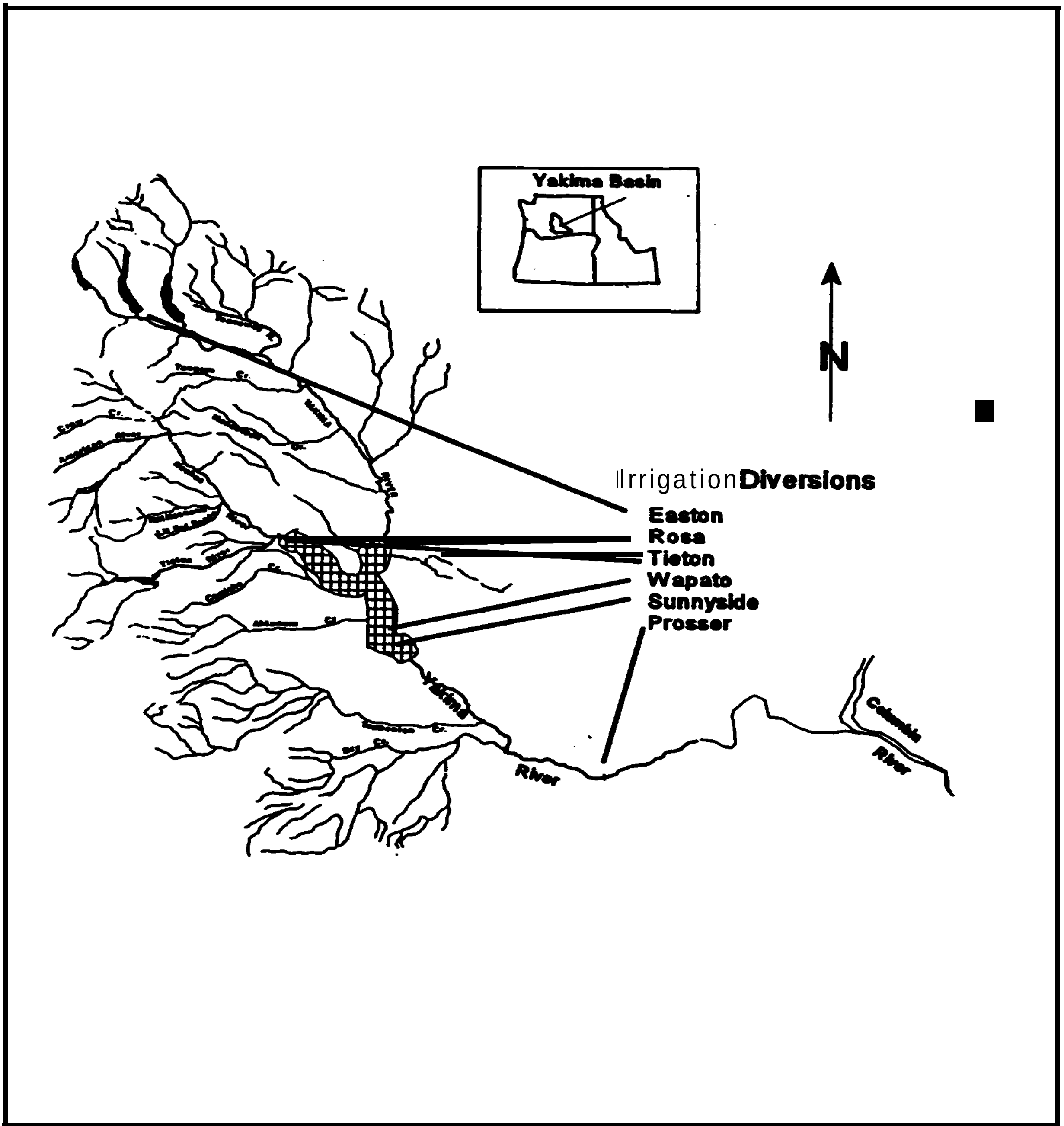


Figure 38. Location of major irrigation diversions and the historic spawning distribution of summer chinook salmon in the Yakima Basin. (From **CTYIN et al.** 1990)

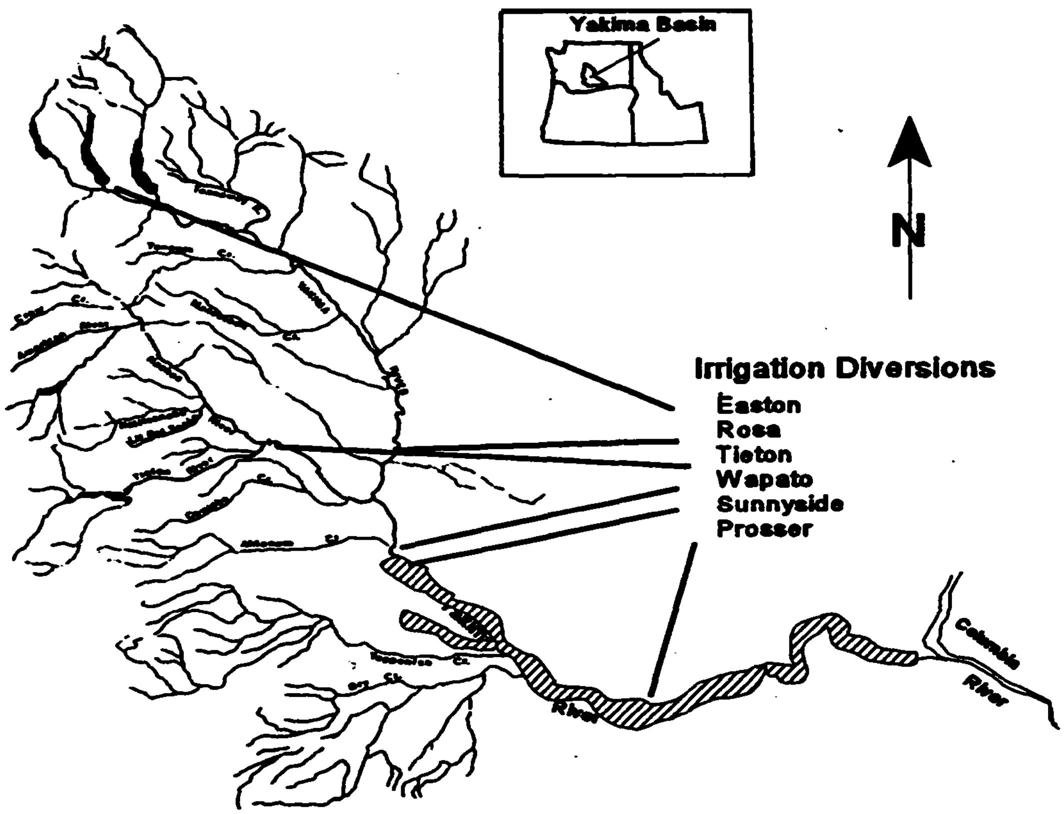


Figure 33. Location of major irrigation diversions and the current spawning distribution of fall chinook salmon in **the** Yakima Basin. **(personal communication; Bruce Watson, YIN, August 31, 1994)**

watered fields. This in large part explains the hypothesized loss of life history diversity in the Yakima Basin (personal communication; Bruce Watson, YIN, 1992).

Land clearing, overgrazing of riparian vegetation, draining of wetlands, channel straightening and water diversions destroyed habitat connectivity within a basin and between the subbasin and the mainstem. Loss of connectivity fragmented the salmon habitat in the mid-Columbia subbasins (e.g. Figures 36 and 37) and is most evident in the lower reaches of those streams (Table 5). The cumulative effects of development dewatered the lower reaches of tributaries or elevated temperatures beyond the preference or tolerance of salmon. The combination of unscreened irrigation diversions and loss of riparian cover created thermal or physical barriers that would have destroyed the ocean type life history pattern in spring and summer chinook salmon. This assumes that stream temperatures under natural instream flows and healthy riparian cover would have remained within the liveable range for juvenile chinook salmon. The latter is a critical uncertainty discussed later in this report.,

There is an interaction between the Intensive harvest and loss of productivity associated with the subyearling life history pattern. The loss of subyearling smolts in irrigation diversions would have significantly reduced the optimum sustained yield in the affected stocks (Junge 1970). Continued high harvest rates combined with shrinking harvestable surpluses would have created a downward spiral and rapid decline in total production as was observed (Figures 14 and 15). The degradation of freshwater habitat and the loss of biodiversity (life histories) in chinook-salmon was more detrimental-than high harvest rates in the long run because the loss of biodiversity and habitat quality limited the possibility of recovery after harvest was brought under control. In addition, the loss of production due to habitat degradation would have focused harvest on fewer stocks causing a rapid decline in escapement in areas such as the Snake River and upper Columbia River.

After 1920, as the fishery shifted emphasis to fall chinook, overall harvest of chinook salmon went into decline. While overharvest and habitat destruction contributed to the rate and depth of the decline, there were natural climatic factors contributing to the decline and probably acting synergistically with the human impacts. The region was experiencing a shift in climate to hot/dry conditions and lower ocean productivities. Attempts to stabilize production during a period of natural decline through the use of hatcheries were probably counter productive (Lichatowich *in press).* Following 1338, the ccnstruction of mainstem dams and continued habitat degradation in the subbasins prevented recovery to historic levels. The mainstem dams also introduced ecological change in the mainstem Columbia. Those changes reduced. habitat quality for juvenile chinook salmon and reduced connectivity between the mainstem and estuarine habitats.

Table 5. Habit suitability for juvenile chinook salmon in the lower reaches of the study subbasins.

Subbasin	Comments on Habitat	Source
Yakima	Lower river below Prosser (RM 47.1) frequently exceeds 75°F and occasionally reaches 80°F in July and August rendering the lower river uninhabitable by salmonids.	CTYIN et al. 1990
Tucannon	Water temperatures in lower river at or above lethal levels.	WDF et al. 1990
Umatilla	Lower 32 miles subject to irrigation depleted flows and temperatures exceeding upper lethal limits for salmonids.	CTUIR and ODFW 1990
John Day	Juvenile chinook salmon generally not found in the river where temperatures reach 68°F. High stream temperature eliminates juvenile rearing habitat in the lower river.	Lindsay et al. 1981, ODFW et al. 1990
Deschutes	In the mainstem Deschutes River, summer temperatures are adequate for chinook salmon. However, there are temperature problems in the lower reaches of the tributaries where spring chinook salmon spawn. In addition *Ceratomyxa Shasta* limit the survival of juvenile chinook salmon in the mainstem through the summer months.	Ratliff 1981, ODFW and CTWSR 1990

This study has pointed to the need for restoration planning that employs a greater use of historical reconstruction and a more inclusive analysis of the salmon's life history. As W. F. Thompson (1353 p. 208) pointed out in our management of Pacific salmon, we attach "far greater importance to that which we see than to that which we do not." One way fishery managers "see' is through the conceptual frameworks and hypotheses that guide specific studies or restoration activities. When managers simplify the system in order to model it, and in the process ignore environmental history, habitat connectivity, life history diversity, or historic conditions of the habitat, their vision is restricted. One result of restricted vision is inadequate problem definition and solution development. Focus is placed on hatcheries and escapements while important contributions to productivity such as life history diversity and habitat connectivity remain outside our vision.

Managers should not abandon models of simplified segments of the salmon's life history and habitat. However, those models and the programs derived from them must be embedded in a broader conceptual framework. The models should be designed to address hypotheses derived from the broader framework. This study is one step in the process of constructing a more inclusive conceptual framework.

DISCUSSION

Biodiversity Hypothesis

The purpose of this study, stated at the beginning of this report, was to evaluate the status of chinook salmon in the streams flowing through the steppe or shrub-steppe ecological zone. The analysis was guided by the working hypothesis that declines in abundance of chinook salmon were due in part to the loss of biodiversity — intrapopulation life history diversity. There is insufficient information to reject the hypothesis. On the other hand, the analysis did not develop conclusive support for the hypothesis. This result is not surprising since the decline in abundance of chinook salmon began before appropriate data on life histories were collected. On balance, the information presented in this-report supports the original working hypothesis. The study has permitted a refinement of the original hypothesis which is presented in this section.

Development of.a modern industrial economy in the Columbia Basin fragmented salmon habitat and eliminated much of the rearing areas used by juvenile chinook salmon. By 1930, 50 percent of the best spawning and rearing areas had been destroyed or degraded (OFC 1933). For Pacific salmon, where migration is a central feature of the juvenile and adult life history, the connectivity among habitats — tributaries, subbasin, mainstem, estuary — is a critical component of ecosystem health (Lichatowich et al. 1995). Salmon habitats can be thought of as a series of seasonally important places where salmon carry out their life histories (Thompson 1959). The presence of those places (structural habitat features) is important but so is the ability to freely move between them at the appropriate times. Loss of connectivity for part of the natural migratory period eliminates life history diversity in a stock.

Chinook salmon are generally characterized as preferring larger rivers and larger tributaries of rivers. They tend to spawn in deeper water and in larger gravel than the other species of Pacific salmon (Scott and Crossmen 1973). If the adult life histories evolved to utiliie the larger reaches of rivers, is it not reasonable to assume that juvenile life histories also evolved to use the larger, lower reaches of tributaries and mainstems of river basins?

The early life history and freshwater distribution of juvenile chinook salmon in Oregon's coastal rivers has been described in this way:

> *"Immediately after emergence from the gravel, distribution of juveniles is restricted to the areas within the river basin where adults spawned, which usually include low to moderate gradient reaches of the mainstems and larger tributaries. By late spring, underyearlings*

are generally well distributed downstream throughout the mainstem riverine reaches and the freshwater tidal reaches of estuaries. We believe that the extent to which some juveniles remain in the riverine reaches during the summer is related to __water temperature__ (emphasis added), with relatively cooler systems suppotting rearing juveniles over a more extended duration. Even in rivers that support a population of rearing juveniles for extended periods, an essentially constant flow of juveniles moving downstream probably occurs. We believe the larger juveniles have a greater tendency than smaller juveniles to move downstream," (Nicholas and Hankin 1989 p. 5 and 8).

In Oregon's coastal basins, the subyearling migrant life history (ocean type) dominates both spring and fall races of chinook salmon, About 95 percent of returning adults exhibited the ocean type life history. The Umpqua River is an exception. In the Umpqua River, both stream and ocean type life histories are strong components of the spring chinook salmon population (Nicholas and Hankin 1989).

The quotation from Nicholas and Hankin (1.989) includes four important points: 1) continuous downstream migration; 2) the influence of temperature on use of the riverine reaches; 3) the selective movement of larger juveniles; and 4) the importance.of the mainstem and estuary as rearing areas. Continuous downstream migration of juvenile chinook salmon is not unique to Oregon's coastal basins. Rich (1920) concluded that juvenile chinook salmon in the Columbia River migrated throughout the entire year with the major migration period from June through October. Rich (1920) speculated that the juvenile chinook salmon migrating at different times in the Columbia River originated in different tributaries with the progressively later migrating fish coming from tributaries further upstream. Further north in the Nanaimo River, juvenile chinook salmon migrate to sea in three pulses one shortly after emergence, a. few months later after a short period of freshwater rearing, and the final group in the spring of the following year. Although the migration was divided into three distinct times of entry to sea, there was a downstream movement by all groups during the first summer. The-different times of migration were related to the location where the spawning took place (Carl and Healey 1984). In some streams, juvenile chinook salmon undertake a slow rearing migration through the mainstems (Beauchamp et al. 1983).

Rearing areas in the mainstems downstream from spawning areas appear to be important in chinook salmon. Even juvenile chinook that overwinter in freshwater often leave the tributaries and move into the mainstem to rear in larger pools through the winter (Healey 1991). In the Columbia Basin, this pattern has been observed in the Yakima River (CTYIN et al. 1990), Grande Ronde River (Burck 1993), Deschutes River (Lindsay et al. 1989), and Lemhi River (Keifer et al. 1993).

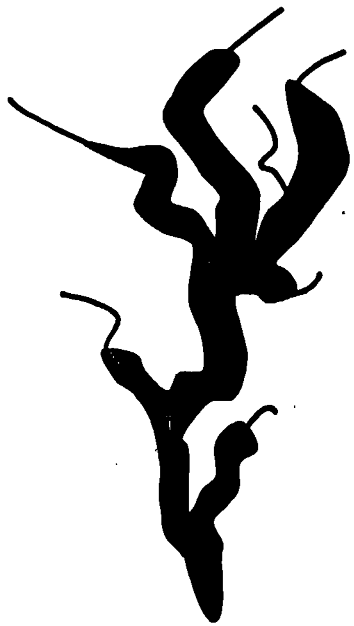
Channel morphology and hydraulics suggest that habitat in the lower reaches of streams is more stable than the upriver areas or tributaries (Naiman et al. 1992; Baxter 1961). The continuous downstream movement of juvenile chinook salmon is in essence a migration towards what were historically the natural centers of habitat stability in the lower reaches of larger tributaries and the mainstem. Today those areas are death traps due to lethal temperatures, predators and mortality at dams.

The continuous downstream migration of juvenile chinook salmon is accomplished by the selective movement of the larger individuals in a population (Nicholas and Hankin 1989). Migration of larger juveniles has been observed in the Columbia River (Rich 1920) and in chinook salmon transplanted to a Michigan stream (Carl 1984). This migration pattern might be explained in this way: Since size is a strong component of mortality rates (Roff 1992) and the lower reaches of rivers historically offered the potential for more stable habitats, the movement of larger juveniles to lower stream reaches has reinforcing survival value.

The lower reaches of mid-Columbia Subbasins have been degraded to the point they are lethal to juvenile salmon (Table 5). Habitat degradation in the lower reaches is largely the result of irrigation withdrawals, grazing and timber harvest. The former reduces flow and influences temperatures. The latter has reduced riparian cover impacting habitat quality and also elevating stream temperatures. The loss of lower mainstems of the subbasins and significant tributaries of subbasins has fragmented the habitat of chinook salmon, in particular the habit of juvenile summer and spring chinook salmon. Habitat fragmentation results from a loss of connectivity among stream reaches which isolates juvenile chinook salmon in the upper reaches of a basin. Juvenile chinook salmon are blocked from completing their normal migration and are confined to refugia (Figures 40-41). The smaller streams in the upper reaches of the basin — the current refugia — were historically less stable and less productive than the lower reaches of the subbasins and mainstems — the reaches where juvenile chinook salmon historically migrated to in a continuous stream through the spring, summer and fall.

Although juvenile chinook salmon may have migrated in a continuous stream, those movement patterns might be partitioned into three overlapping migrations: the first in early spring consisting of fry and yearling smolts, the second in midsummer consisting of subyearling migrants destined to enter the sea that year, and a third downstream movement of subyearlings in the fall. Juveniles in the latter migration go to sea the following spring (Figures 4041). Within a given subbasin, when spring chinook salmon have sufficient growth opportunity and

A



B

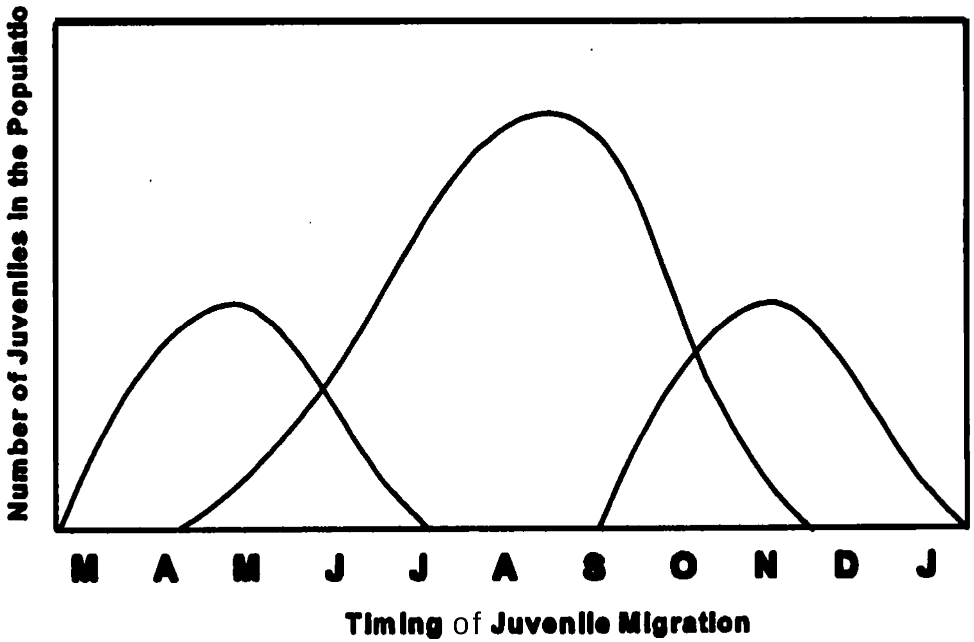


Figure 40. Hypothetical portrayal of highly connected habitats (shaded area In A) in a watershed and the distribution of migration patterns of juvenile chinook salmon In the same basin (B).

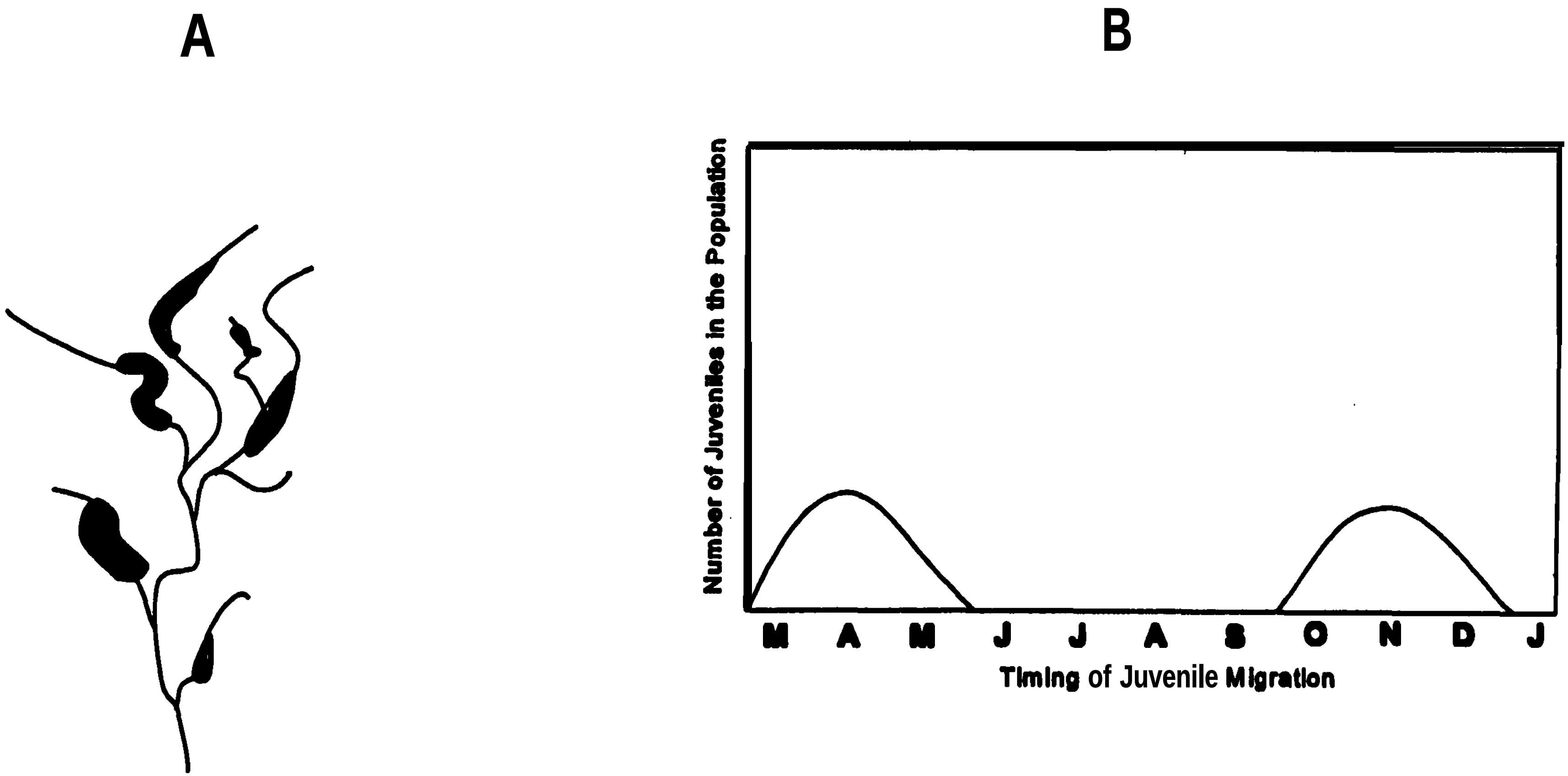


Figure 41. Hypothetical portrayal of fragmented habitats (shaded area A) disconnected from the lower reaches of tributaries and the mainstem by lethal conditions and the resulting migration patterns of juvenile chinook salmon in the same basin (B).

habitat connectivity, the ocean type life history pattern emerges as an important component of a population's productivity. As habitats are fragmented, the ocean type life history is reduced or eliminated (Figures 40–41).

How might the hypothesis presented here alter our thinking or approaches. to restoration? Here is an example:

Suppose a subbasin has lost connectivity with the mainstem with a resultant loss of life history diversity and productivity of 2the stock. One conventional approach is to "open up" new -habitat in the upper reaches of the subbasin by laddering falls or other natural barriers. When the problem is viewed from the life history/habitat perspective, it becomes obvious that creating more habitat in the upper basin will not reduce the lower river production constraint.

The decline in abundance of chinook salmon, in particular the spring and summer races, was the outcome of habitat degradation and persistent high harvest rates. Habitat degradation reduced life history diversity and productivity of the spring and' summer races. Continued harvest aggravated the effects of lost biodiversity. Further habitat degradation and continued harvest accelerated the rate of decline during a period of hot/dry climate and low ocean productivity. By the 194Os, a firmly entrenched agricultural system that diverted water and destroyed riparian vegetation and mortality at mainstem dams prevented any possibility of recovery to pre-1 920s production levels.

The biodiversity hypothesis illustrated in Figures 40 and 41 is a consequence of viewing the decline of salmon through the lens of a different conceptual framework – a framework articulated in the early sections of this report. The life history-habitat or biodiversity hypothesis should not be considered an all-encompassing solution or approach to the restoration of Pacific salmon in the Columbia River, on the other hand, the biodiversity hypothesis and its conceptual framework should not be ignored. In a basin the size of the Columbia River, there is room for and in fact a need for conceptual pluralism. The alternative to conceptual pluralism is consensus driven dogma which stifles the creativity and problem solving power of science. At a minimum the conceptual framework for large programs should be explicitly stated. Too often that is not the case (e.g., Whitney et al. 1993).

Uncertainty

It is uncertain whether theconditions in the lower reaches of the study subbasins ever did maintain salmon habitat through the summer months, especially temperatures suitable for summer rearing and migration of juvenile chinook salmon. The study subbasins are all high desert streams where warm summer climate and low rainfall are normal. Conditions in the lower reaches of those streams may have always been marginal or lethal.

There can be little doubt that these subbasins represent marginal habitat and that they were very sensitive to degradation following settlement. Severe habitat degradation took place early, before the turn of the century, and there is at least anecdotal information that salmon populations were much larger in the study basins historically than today. If the biodiversity hypothesis for the mid-Columbia streams is rejected, one would have to conclude as an alternative that the millions of yearling juveniles (stream type) needed to produce the historic abundance of spring and summer chinook salmon were capable of rearing in the restricted habitats available today.

The subbasins included in this study may have undergone natural restriction in life history diversity in response to climate cycles. The hot/dry climate during the 192Os, 193Os, and 194Os, for example, might have naturally reduced flow and elevated temperatures eliminating or reducing the subyearling migrant life history. The decline in harvest of chinook salmon initiated in 1920 (Figure 38) was in part a natural decline. The rate of the decline and the depth of the trough was aggravated by habitat degradation and harvest. The natural loss and recovery of life history patterns and populations with changing climate and habitat suitability is consistent with the concept of metapopulation structure (Hanski and Gilpin 1991; Reiman and McIntyre 1993). Irrigation withdrawals, habitat degradation and mainstem dams prevented the natural recovery of chinook salmon following a shift to a more favorable climate pattern. What recovery that did occur (E and F in Figure 35) did not even begin to approach the former abundance.

The uncertainty regarding natural temperature regimes can be addressed in two ways. The spacing of growth rings on freshwater mussels are an accurate reflection of the temperature of the mussel's environment. Stream temperatures can be backcalculated from the increments of shell growth of freshwater mussels (Chatters *in press).* Shell middens in the Yakima Basin could be examined and historic temperatures reconstructed. This approach has a reasonable chance of successfully resolving the question, 'Were the predevelopment temperatures in the lower Yakima River compatible with usage by juvenile salmon?" (personal communication; James Chatters, Nonh American Paleoscience, Richland, WA).

An alternative approach is the restoration of natural riparian zones and flows in a selected subbasin to determine if the subyearling life history reexpresses itself. This approach would be expensive and it would disrupt the patterns of land and water use that have been in place for a century or more. However, restoring habitat connectivity is consistent with the restoration of salmon from within an ecosystem perspective. Approaching restoration from an ecosystem perspective, which seems to be the emerging consensus, will at some point require adaptive programs scaled to the watershed or ecosystem level of organization. Reconnecting the parts of the subbasin in a way that reestablishes life history diversity could prove to be as beneficial to salmon production and productivity as improving survival at the mainstem dams. Restoring connectivity between the mainstem and the subbasin, however, will probably be much more difficutt to achieve.

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